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The time course of colour congruency effects in picture naming

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ABSTRACT

In our interactions with people and objects in the world around us, as well as in communicating our thoughts, we rely on the use of conceptual knowledge stored in long-term memory. From a frame-theoretic point of view, a concept is represented by a central node and recursive attribute-value structures further specifying the concept. The present study explores whether and how the activation of an attribute within a frame might influence access to the concept's name in language production, focussing on the colour attribute. Colour has been shown to contribute to object recognition, naming, and memory retrieval, and there is evidence that colour plays a different role in naming objects that have a typical colour (high colour-diagnostic objects such as tomatoes) than in naming objects without a typical colour (low colour-diagnostic objects such as bicycles). We report two behavioural experiments designed to reveal potential effects of the activation of an object's typical colour on naming the object in a picture-word interference paradigm. This paradigm was used to investigate whether naming is facilitated when typical colours are presented alongside the to-be-named picture (e.g., the word "red" superimposed on the picture of a tomato), compared to atypical colours (such as "brown"), unrelated adjectives (such as "fast"), or random letter strings. To further explore the time course of these potential effects, the words were presented at different time points relative to the to-be-named picture (Exp. 1: −400 ms, Exp. 2: −200 ms, 0 ms, and + 200 ms). By including both high and low colour-diagnostic objects, it was possible to explore whether the activation of a colour differentially affects naming of objects that have a strong association with a typical colour. The results showed that (pre-)activation of the appropriate colour attribute facilitated naming compared to an inappropriate colour. This was only the case for objects closely connected with a typical colour. Consequences of these findings for frame-theoretic accounts of conceptual representation are discussed.

1. Introduction

How we mentally represent information about the world we live in, how we learn and form memories, and how we use these representations in communication has been the subject of study and debate for a long time (for an overview, see Murphy, 2004). An influential notion of the format of conceptual representations that we adopt in the present paper are so-called Barsalou frames (Barsalou, 1992; Gamerschlag, Gerland, Osswald, & Petersen, 2015). Barsalou (1992) proposed frames, in the form of recursive attribute-value structures, as the general format of conceptual representation. Originating in the field of artificial intelligence (Minsky, 1974), the notion of conceptual frames has since entered other fields such as psychology, linguistics, and philosophy, and has become a widely-used format in the study of mental representations. Attributes within frames assign properties to the object described by the frame (e.g., the attributes *colour* or *form* in the frame of tomato). An attribute's value further specifies the property (e.g., [*colour*: red] or [*form*: round]).

A question that is still under debate is the exact nature of attribute-value structures within frames, and how they interact with language use. In the present paper, we not only explore the way attributes and values are stored in frames (located at the *conceptual level* of representation), but also how we access words for a concept we would like to refer to (*lemma retrieval*). Specifically, we are interested in whether and how the availability of an attribute within a frame might influence lexical access.

A widely used experimental paradigm to study lexical access and the time course of object naming is the Picture-Word Interference paradigm (PWI, e.g., Glaser & Glaser, 1989; Schriefers, Meyer, & Levelt, 1990; Lupker, 1979; Roelofs, 1992). In this paradigm, participants are

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instructed to name a picture of an object (the target, e.g., *horse*) presented on a computer screen. Alongside the picture, another word or picture is presented on the screen, superimposed on or in the periphery of the target picture (the distractor, e.g., *cow*). The distractor stimulus can be presented simultaneously with the target picture (e.g., the word *cow* superimposed on the to-be-named picture of a *horse*), shortly before the picture (negative stimulus onset asynchrony or SOA), or shortly after the picture (positive SOA). By varying the type of distractor stimulus, presentation order and timing, it is possible to study context effects of the distractor on different processing stages of naming the target picture.

Varying SOA allows the researcher to draw conclusions about the time course of the effects. By presenting the distractor before, at the same time or after the target picture, the distractor stimulus can be introduced during conceptual, lexical, or post-lexical stages of naming the target, respectively (Damian & Martin, 1999; Schriefers et al., 1990). In this way, conclusions can be drawn as to the processing stage that is affected by the relation between distractor and target picture.

Previous research has shown that different types of semantic relationship between distractor and target can lead to different effects on naming latencies: If distractor and target are members of the same semantic category (e.g., *cow* and *horse*), a semantic interference effect (SIE) compared to unrelated distractors (e.g., *ball* and *horse*) can be observed. The SIE has been generally interpreted as reflecting competition among co-activated entries in the mental lexicon during lexical access (Schriefers et al., 1990, but see Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). Following this interpretation, a target picture such as HORSE activates not only the concept *horse*, but also related concepts sharing similar semantic attributes, such as *cow* and *zebra*. If a semantically related distractor word (e.g. *cow*) is superimposed upon the target picture *horse*, the semantically related concept denoted by the distractor receives additional activation. The activation then spreads to the lexical level, increasing activation levels for entries corresponding to the activated concepts. These lexical entries then compete for lexical selection, until the entry that ultimately receives the highest activation is selected. Since not only the lexical entry corresponding to the target (*horse*), but also the lexical entry corresponding to the distractor word (*cow*) are highly activated, competition for lexical selection is increased in comparison to presentation with an unrelated distractor (e.g., *ball*). This increased competition results in longer naming latencies.

However, in PWI paradigms, distractors do not in all cases interfere with naming: If distractor and target are associatively related (e.g., *cheese* and *mouse*), facilitation has been observed at SOAs between −300 and 0 ms (Alario, Segui, & Ferrand, 2000; Bölte, Jorschick, & Zwitserlood, 2003; Hirschfeld, Jansma, Bölte, & Zwitserlood, 2008; Jorschick, Bölte, Katzenburg, & Zwitserlood, 2005; Sailor, Brooks, Bruening, Seiger-Gardner, & Guterman, 2009). More rarely, null-effects (Lupker, 1979) or even interference (Cutting & Ferreira, 1999) have been reported. The facilitatory effect of associatively related and part-of distractors has been interpreted as evidence against competitive accounts of lexical selection (e.g., but see Abdel Rahman & Melinger, 2009a for a defence of the competition account).

So far, there is a research gap when it comes to the study of specific conceptual attributes and how their activation influences naming. There has been some research on the activation of distractor-target pairs that stand in a part-whole relation (e.g., *roof* – *house*). For these part-whole relations, there is diverging evidence on whether they produce facilitation or inhibition: Whereas Costa, Alario, and Caramazza (2005) and Muehlhaus et al. (2013) found facilitation at SOA 0 ms for distractor-target pairs such as *bumper* – *car*, Sailor and Brooks (2014) failed to replicate their results, and suggested that the associative relation between distractor and target might the driving factor behind facilitatory effects (see also Piai, Roelofs, & van der Meij, 2012). Sailor and Brooks (2014) found that only associatively related distractor-target pairs produced facilitation at SOA −300 and -150 ms (but not at SOA 0 ms). Conversely, parts that were not associated with the target produced interference at SOA 0 ms. Similarly, for distractors denoting a distinctive feature of the target, such as *hump* – *camel,* Vieth, McMahon, and de Zubicaray (2014) found interference at short negative SOAs.

In the current study, we focused on activating the value of an attribute, namely colour. Since colour is a surface feature of an object, studies investigating surface attributes are of particular interest. For distractor-target pairs such as *fur* – *dog*, a study by Hirschfeld et al., 2008; see also Jorschick et al., 2005 showed facilitation at SOA 0. With respect to colour attributes, previous research has provided evidence that colour might play a different role in naming objects that have a typical colour (high colour-diagnostic objects such as *banana*; HCD) than for objects with no typical colour (low colour-diagnostic objects such as *bicycle*; LCD). For instance, naming of HCD objects is facilitated when the object is correctly coloured as opposed to when it is presented in an incongruent colour or in black and white, whereas LCD objects do not seem to benefit from the additional colour information as much as HCD objects (Price & Humphreys, 1989; Therriault, Yaxley, & Zwaan, 2009; Redmann, FitzPatrick, Hellwig, & Indefrey, 2014, Exp. 1; for a meta-analysis see Bramão, Reis, Petersson, & Faísca, 2011; but see Biederman & Ju, 1988 and Davidoff & Ostergaard, 1988, who did not find an effect of surface colour on object recognition). Using distractors in the form of coloured rectangles paired with HCD and LCD target objects, Redmann et al. (2014) found no effect of a congruent colour distractor on reaction times compared to a distractor consisting of an achromatic checkerboard pattern. However, an analysis of electrophysiological data collected during naming revealed an increased amplitude of the P2 component in the Event-Related Potentials in reaction to HCD objects (e.g., *tomato*) preceded by a typically coloured distractor (e.g., a red rectangle) as compared to the checkerboard distractor. Since the P2 component has been interpreted as reflecting relative difficulty of lexical access (Costa, Strijkers, Martin, & Thierry, 2009; Strijkers, Costa, & Thierry, 2010), these results suggested that at an SOA of -400 ms, colour distractors hinder lexical access of the target word.

Redmann et al. (2014) interpreted these findings along two lines of reasoning: On the one hand, the P2 effect of colour priming might be related to the specific nature of the colour attribute in the frame. In the case of the frame for tomato, the value of the colour attribute might be a general shade of red or a particular tomato-red. Assuming the value consists of a particular shade of colour, it is conceivable that the colour chosen for the colour box in the experiment might not have corresponded exactly to the shade of colour represented in the target's frame. On the other hand, the colour box may have activated a large set of objects that share a typical colour, whereas the checkerboard used in the control condition activates a much smaller set of possible competitors (e.g., *chess* or *pawn*). As a consequence, more competing lemmas would be activated at the lexical level for objects primed with their typical colour, resulting in increased lexical competition compared to the control condition. This competition would be largest in the case of HCD objects, because they often share shape features in addition to their typical colour (cf. *tomato*, *strawberry*, *raspberry*, and *cherry*). This line of explanation suggests that only the central node in a frame can be used for lexical access, whereas single attribute nodes cannot. If single attributes had access to the lemma, a facilitatory effect of colour priming would be expected. The fact that a detrimental effect of colour priming was found would point to a conceptual organisation in frames that resembles non-decompositional views of conceptual representation instead. Considering only the results from Redmann et al. (2014), we were not able to distinguish between these two lines of explanations.

The main goal of Experiment 1, thus, was to test the first of the two hypotheses: Could inhibitory priming of typical colours in the study reported by Redmann et al. (2014) be due to a mismatch between the colour activated by the colour prime (a specific combination of hue, saturation, and brightness; Munsell, 1905) and the stored object-colour knowledge in long-term memory? In Experiment 1, we tested this hypothesis by replacing the colour box with an adjective denoting the target's typical colour, an atypical colour or an unrelated adjective in a PWI paradigm.

2. Experiment 1

2.1. Design and objective

To address the possibility that a colour box could mismatch the specific colour connected with a particular object, a set of colour adjectives instead of colour boxes was chosen as distractors. Colour representations are routinely activated by reading colour words (Richter & Zwaan, 2009). Moreover, colour adjectives have been shown to activate larger portions of the spectrum corresponding to a particular colour (most likely their respective prototypical shade, i.e., focal colours in the sense of Rosch, 1973, and some area in the spectrum around it with language-specific, fuzzy borders, Berlin & Kay, 1969; Šuchová, 2014). Therefore, in Experiment 1, colour adjectives referring to the typical colour of the to-be-named object were presented as distractors (e.g., *red* – *tomato*). As control conditions, we chose atypical colour words (e.g., *white* – *tomato*) and adjectives representing attributes that were incompatible with the target objects (such as *fast* – *tomato*, representing a *speed* attribute that is unlikely to be present in the tomato frame). Provided colour words activate the shade of colour that is represented in the concept's frame (among other shades), we expect facilitated lexical access reflected in faster reaction for HCD objects paired with their typical colour compared to an atypical colour or an unrelated adjective. In accordance with the results found in Redmann et al. (2014), we would again expect this congruency effect to be absent for LCD objects, which do not have a typical colour whose pre-activation could facilitate lexical access.

The behavioural data presented here as Experiment 1 in the following were collected in the context of an EEG study, in which we also assessed the effect of the colour word manipulation on the P2 component. Since the data were inconclusive with respect to the P2 component (see Redmann, 2019), we only report the behavioural data here.

2.2. Methods

2.2.1. Participants

A total of 36 participants (mean age 22.7 years with a standard deviation of 3.13 years, 26 female) took part in the experiment, which was conducted at the Donders Institute for Brain, Cognition and Behaviour, Nijmegen, the Netherlands. Six of these participants were excluded from further analyses because of recording errors (5 participants), or because the participant was not a native speaker of Dutch (1 participant). All 30 participants included in the analysis were right-handed native speakers of Dutch with normal or corrected-to-normal vision, no colour vision impairment and no known neurophysiological deficits. As a reward for participation, they received study credit or money.

2.2.2. Materials

In order to choose stimulus materials for Experiment 1, we conducted a rating study to determine degree of colour-diagnosticity, naming agreement, familiarity and difficulty of recognition for all items used in this study. We included a total of 303 pictures from the Snodgrass and Vanderwart picture set (Snodgrass & Vanderwart, 1980) and the picture database from the Max Planck Institute for Psycholinguistics in Nijmegen, Netherlands, in the rating study (see Fig. 1 for an example of our stimulus materials and trial sequence).[1] Twenty-four

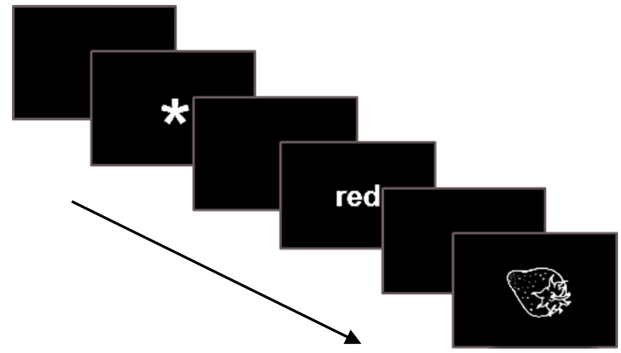

Fig. 1. Example of a typical trial sequence in Experiment 1 (high colour-diagnostic object with typical colour distractor).

native speakers of Dutch, mostly undergraduate students at Radboud University, Nijmegen, the Netherlands, took part in the rating study. Participants were presented with all prospective stimulus pictures on a computer screen. For each picture, they answered the following questions. All questions were presented in Dutch.

1) "What do you see in this picture?"
2) "Does this object have one (or more) typical colours?"
3) "How often do you encounter this object in your daily life (also in the media or in your thoughts)?"
4) "How easy was it to recognise the picture?"

Participants were instructed to answer questions 3 and 4 on a scale from 1 to 5. If a participant judged an object as having one or more typical colours, he or she was subsequently prompted to enter up to six typical colours from most to least likely. Our criteria for choosing items for our stimulus sets based on the results were the following: There was a naming agreement above 75% across participants (naming agreement indicates the percentage of participants giving the same name to a given object). The dominant name was chosen as the expected answer to the target picture and was used for further matching of linguistic properties of expected responses between conditions. Colour-diagnosticity was determined as the percentage of participants who indicated that a particular object had a typical colour (answer "yes" to question 2). Prior to calculating this percentage, we excluded all answers in which the subject did not recognise the picture (either because they indicated in their answer that they did not recognise the picture, or because they gave a name that did not correspond to the picture, e.g. "horse" for the picture of a donkey). Only objects with a colour-diagnosticity percentage over 60% were included in the HCD item set, whereas all low colour-diagnostic objects had a percentage below 40%. There was no forward association between colour words and HCD objects (e.g., red – tomato), with the exception of three objects (*frog*, *banana*, *sun*, association values taken from Nelson, McEvoy, & Schreiber, 1998). This procedure yielded a total of 75 HCD and 75 LCD objects that were used as experimental items in the experiment. HCD and LCD objects were matched along the following dimensions: word length in syllables, log of word frequency per million words indicated by the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993), object familiarity and difficulty of recognition (Table 1). There was an imbalance in terms of the number of natural and artificial objects, a problem that has been described previously by researchers conducting studies on colour-diagnosticity (Bramão et al., 2011). Since this inherent imbalance could not be resolved, the natural-artificial distinction has to be taken into

[1] Line drawings were used instead of photographs as in the study reported by Redmann et al. (2014), because they exhibited overall higher naming agreement rates and lower difficulty of recognition, so that loss of trials due to naming errors would be minimized. As was shown in the meta-analysis by

(*footnote continued*)
Bramão et al. (2011), effects of colour-diagnosticity were present for both photographs and line drawings, and particularly large for line drawings from the Snodgrass and Vanderwart set.

Table 1
Summary statistics for matching factors between high and low colour-diagnostic (HCD, LCD) stimuli in Experiment 1.

	CD % (mean)	Word length (mean)	Frequency (mean)	Familiarity (mean)	Difficulty of recognition (mean)	Natural objects (N)	All objects (N)
HCD	86.6	1.8	2.2	2.8	1.3	47	75
LCD	13.9	1.8	2.3	3.0	1.2	16	75

account when interpreting differences between HCD and LCD stimuli. Note that in their meta-analysis on colour-diagnosticity and object recognition, Bramão et al. (2011) found that processing of both natural and artificial objects was affected by surface colour information.

Distractors words were inflected in accordance with their respective target word and its grammatical gender in Dutch (e.g. $gele_{common\ gender}$ – $banaan_{common\ gender}$; "yellow banana"), to avoid participants perceiving a gender congruence violation between the visually presented adjective and the noun they produced. Since adjectives are inflected differently when modifying grammatically neuter nouns compared to common gender nouns in Dutch, we matched the number of grammatically neuter target words across conditions (4 per condition in all conditions). We chose the sets of adjectives presented as distractors based on the following criteria: As typical colour, we chose the colour that was named most often for a HCD object in the rating study. Atypical colours were colours that were not named by any participant for a given HCD object in the rating study. The colour adjectives used in the typical and atypical colour conditions were: *bruin* (brown), *geel* (yellow), *gouden* (gold), *grijs* (grey), *groen* (green), *oranje* (orange), *rood* (red), *wit* (white), *zilveren* (silver), and *zwart* (black). Unrelated adjectives were semantically incongruent as properties of the object and are not likely to be present as an attribute in the frame (e.g., *fast – tomato*). The inflected colour adjectives and unrelated adjectives were matched in terms of word length and frequency according to CELEX (Baayen et al., 1993). For normalisation, we applied log natural transformation of the frequency count per million +1 (colour adjectives: mean log freq. 3.8, mean syllable count 1.5; unrelated adjectives: mean log freq. 4.1, mean syllable count 1.4). For LCD objects, adjectives in both colour conditions could be considered congruent colours for the object. This procedure resulted in six experimental conditions: Two sets of objects (HCD vs. LCD objects) paired with three different distractor types (typical colour, atypical colour, unrelated adjective).

A total of thirty experimental lists of trials were created, such that each participant saw a unique list. To ensure that distractor adjectives appeared equally often throughout the experiment for every participant, 150 filler items paired with the three distractor types were included per list in addition to the 150 experimental items. Every participant was presented with every HCD and LCD item paired with all three possible adjectives chosen as distractors for this item, resulting in three presentations of the same item per participant (3 blocks). When averaging over block, this procedure resulted in 75 items per condition. Items in blocks were pseudo-randomised using the Shuffle software (Pallier, 2002), with the constraint that no more than two subsequent trials were of the same condition, and that adjectives and target onset syllables were not repeated on subsequent trials. Blocks were counterbalanced across participants to avoid carry-over effects.

2.2.3. Procedure

Prior to the experiment, all participants filled out consent and screening forms, ensuring that participation requirements were met. After electrode application, participants were tested individually in a dimly lit, acoustically shielded cabin. Before starting the experiment, written instructions for the experiment were presented both in printed form and on screen. Participants were instructed to name each picture as fast and accurate as possible in Dutch, to speak clearly and to avoid blinking or other movements when a fixation cross or picture was visible on screen. Stimulus presentation was controlled using the Presentation® software (Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). The participants' verbal responses were recorded as wav files, and response latencies were determined offline using the Praat software (Boersma & Weenink, 2018). Target pictures were presented in the centre of the screen at a size of 300 by 300px (1028 by 768 screen resolution and a refresh rate of 60 Hz), in white on a dark grey (RGB: 43,43,43) background. Distractor words were presented in white at a size of 14 points in the font "Arial", also in the centre of the screen.

After receiving the instructions, participants completed five training trials consisting of filler items, after which they had the opportunity to ask any remaining questions about the task to the experimenter. At the beginning of each training and experimental trial, a fixation cross was presented for 2000 ms, followed by a blank screen (duration between 0 and 200 ms). Then, an adjective (depending on the experimental condition, denoting a typical colour, an atypical colour, or an unrelated adjective) was shown in the centre of the screen for 200 ms with an interstimulus interval (ISI) of 200 ms before presentation of the target picture (resulting in an SOA of -400 ms). The target was presented for 2000 ms. A blank screen was shown between trials for 3000 ms. Participants were instructed to avoid eye-blinks as soon as they say the fixation cross until they had completed saying the name of the picture, and to blink between trials. The experiment lasted around 120 min including eight self-paced breaks.

2.2.4. Data analysis

Naming errors were defined as trials in which participants gave no response, did not recognise the picture, uttered another word or syllable (e.g., discourse markers such as "ehm") before the actual response, or answered with a word that was not part of our set of item names. All such naming errors and trials with naming latencies > 3 standard deviations (SD) below or above the mean for a particular subject and condition or longer than 2500 ms were excluded from the analysis (13.71% of all trials). Items with exceptionally high error rates after outlier correction were considered unreliable and excluded from further analyses (1 HCD, 1 LCD item).

To test for the presence of main effects and interactions in the data, we used mixed linear models (LMMs) in R (package lme4, Bates, Mächler, Bolker, & Walker, 2015). We tested for main effects and interactions between the following fixed effects: Colour-Diagnosticity (HCD, LCD), Distractor Type (typical colour, atypical colour, unrelated adjective) and Block (1,2,3). For all analyses, we strived to include the maximal random error terms justified by our design, as suggested by Barr, Levy, Scheepers, and Tily (2013). In cases where the model did not converge, we followed Barr et al. (2013)'s recommendations to simplify the random effects structure, making sure that wherever possible, random effects are present for all fixed effects of interest (Barr et al., 2013, p. 276). In cases of non-convergence of a model including random slopes for all effects of interest, we followed Barr et al. (2013)'s suggestion to conduct separate analyses of the model, keeping fixed effects and random intercepts constant, varying random slopes for all predictors of theoretical interest. If all converging analyses were significant, we considered the result generalisable with respect to this predictor.

To test for the presence of main effects, we compared a minimal model containing only random intercepts for subject and item as well as the maximally possible random slope structure to the same model containing the predictor of interest (following the procedure suggested by Winter, 2013). If a subsequent Likelihood Ratio Test showed that the model containing the predictor was a significantly better fit than the simple model, we considered the main effect to be significant. A similar procedure was applied to test for interactions: Whenever a model containing the interaction between two predictors was a significantly better fit than a model containing additive effects, the interaction was considered significant. Planned contrasts and post-hoc tests were carried out using Least Mean Squares with the R package "lsmeans", which uses a Satterthwaite method to obtaining degrees of freedom (Lenth, 2016). Since we expected naming latencies for HCD objects with typical colour distractors to be shorter compared to the atypical colour and unrelated adjective distractors, all p values reported are one-sided for planned contrasts. Throughout all analyses, we used a significance criterion of $p < 0.05$. All post-hoc comparisons were Bonferroni-corrected. Prior to analysis, we log-transformed all reaction time data (natural logarithm), since the raw reaction times exhibited a positive skew, and plots of the model residuals suggested skew and heteroscedasticity.

To analyse naming errors, we used generalised linear mixed models (GLMM) and compared them in the same manner as described for the reaction time analysis. Planned contrasts and Bonferroni-corrected post-hoc comparisons were conducted using the function glht() (package "multcomp", Hothorn, Bretz, & Westfall, 2008).

2.3. Results

2.3.1. Reaction times

All reported models in this section were specified with random intercepts for subject and items as well as by-subject slopes for Colour-Diagnosticity and by-item slopes for Distractor Type.[2] Unless otherwise noted, significant main effects, interactions, contrasts or post-hoc comparisons remained significant at $p < 0.05$ using all other theoretically justified random effect structures that did not result in non-convergence of the model estimation procedure. Mean reaction times are displayed in Fig. 2.

Colour-Diagnosticity affected reaction times ($\chi^2(1) = 9.121$, $p = 0.003$): HCD objects were named more slowly than LCD objects by on average 43 ms. There was no main effect of Distractor Type ($\chi^2(2) = 0.291$, $p = 0.864$), but a main effect of Block ($\chi^2(2) = 1051.5$, $p < 0.001$). Naming responses were 80 ms faster on the second block compared to the first block ($t(11{,}280.72) = 22.582$, $p < 0.001$), and 34 ms faster on the third block compared to the second block ($t(11{,}272.60) = 10.065$, $p < 0.001$). There was no significant interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(2) = 0.5512$, $p = 0.759$), and no three-way interaction between Colour-Diagnosticity, Distractor Type and Block ($\chi^2(12) = 8.4771$, $p = 0.747$).

To be able to better compare the present results with the results obtained by Redmann et al. (2014), which featured only one presentation of each item (as was also the case in previous studies on associative facilitation by, e.g., Muehlhaus et al., 2013), we also analysed the first block separately.

As suggested by the overall analysis, there was a main effect of Colour-Diagnosticity present in the first block ($\chi^2(1) = 6.7461$, $p = 0.009$), and no main effect of Distractor Type ($\chi^2(1) = 0.28$, $p = 0.869$). The interaction between Colour-Diagnosticity and Distractor Type in the first block did not reach significance ($\chi^2(2) = 5.2107$, $p = 0.074$). Planned contrasts aimed at exploring the congruency effect (comparing HCD objects with their typical colour as distractor to an atypical colour and an unrelated adjective) revealed that on the first block, HCD objects preceded by their typical colour were named on average 26 ms faster than when preceded by an atypical colour ($t(130.46) = -1.935$, $p = 0.027$). There was no significant difference between the typical and atypical colour distractor condition for LCD objects ($p = 0.90$). All other contrasts and post-hoc comparisons were also non-significant.

[2] In the following, we report models including this random effects structure, because it was the maximally possible one that could consistently be used for all models within this experiment.

2.3.2. Error rates

There was no significant main effect of Colour-Diagnosticity ($\chi^2(1) = 0.1359$, $p = 0.712$) or Distractor Type ($\chi^2(2) = 1.1998$, $p = 0.549$, see Table 2 for mean error rates). There was, however, a significant main effect of Block ($\chi^2(2) = 82.774$, $p < 0.001$): On the second block, fewer naming errors were made compared to the previous one ($z = -7.470$, $p < 0.001$), however, Block two did not differ significantly from Block three ($z = -0.781$, $p = 1$). We found no interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(2) = 0.362$, $p = 0.834$), and no interaction between Colour-Diagnosticity, Distractor Type and Block ($\chi^2(12) = 12.561$, $p = 0.402$). The analysis of the first block revealed no significant main effects or interactions (all $p > 0.05$). No planned contrasts or post-hoc comparisons reached significance.

2.4. Discussion

2.4.1. Colour-diagnosticity

In line with earlier findings, Experiment 1 showed a clear reaction time effect of colour-diagnosticity: HCD objects were named more slowly than LCD objects. This finding replicates the results from Redmann et al. (2014) and other studies in the literature (e.g., Bramão, Faísca, Petersson, & Reis, 2010; Tanaka & Presnell, 1999). Note that even though a direct comparison between HCD and LCD objects was not possible in the present study, other studies have found that presentation of the object with and without correctly coloured surface differently affected HCD and LCD objects (e.g., Bramão et al., 2010; Redmann et al., 2014). Possible explanations for this effect will be discussed in the General Discussion section below.

2.4.2. Congruency effect

Crucially, reaction times in Experiment 1 also revealed a congruency effect: On the first presentation, HCD objects were named faster when preceded by a colour word denoting their typical colour (e.g., *red* - *tomato*) compared to an atypical colour (e.g., *brown* - *tomato*). The congruency effect found in Experiment 1 contrasts with the results reported by Redmann et al. (2014), where coloured boxes were used as distracters and no behavioural differences as a function of distractor type (typical colour vs. black and white checkerboard pattern) were found. The presence of a behavioural congruency effect in Experiment 1 is consistent with the hypothesis that in the study reported by Redmann et al. (2014), a shade of colour was chosen as a distractor that did not fully correspond to the colour represented as a value of the colour attribute in the object's frame, and thus failed to prime the object's colour feature at a conceptual level. Activating a wider range of colours by means of a colour word in Experiment 1 produced the expected facilitatory effect, suggesting the colour attribute could be pre-activated via the colour word and in turn boost activation of the target concept, and subsequently, the target lemma.

Our finding that congruent compared to incongruent colour words only primed object naming in the first block but not in subsequent blocks is in line with other observations suggesting that naming an item for the first time is different from naming it on subsequent presentations. Perhaps most relevant is a study by Aristei, Melinger, and Abdel Rahman (2011) who observed faster picture naming latencies for associatively related compared to unrelated distractors only on first presentations but not on second and third repetitions. In addition to manipulating the type of distractors, Aristei et al. (2011) also compared picture naming in homogenous and heterogeneous context and

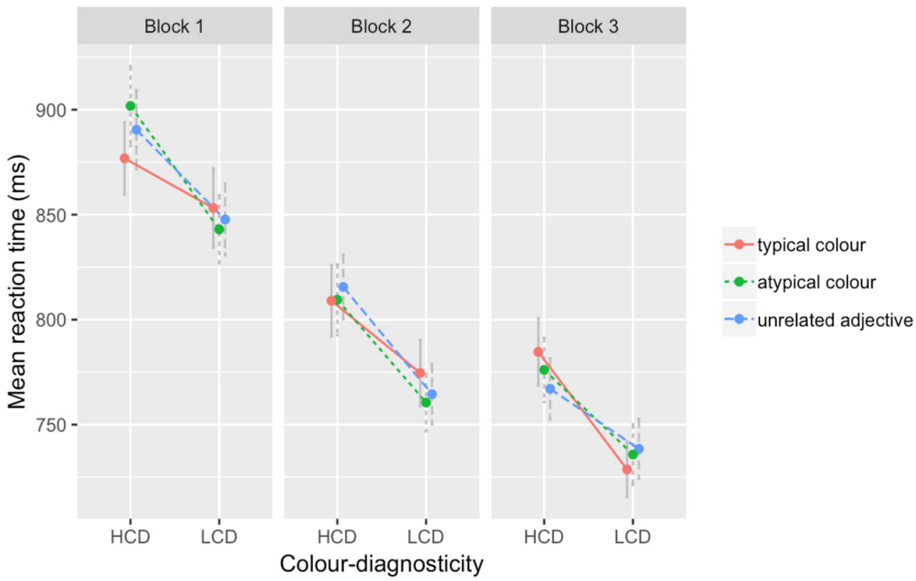

Fig. 2. Mean reaction times in ms for high and low colour-diagnostic objects (HCD, LCD) paired with typical colour (TC), atypical colour (AC) or unrelated adjective distractor (UA) for the three blocks (1,2,3) in Experiment 1. Error bars indicate 95% confidence intervals around the mean calculated using participants as id variable.

Table 2
Mean error rates for high and low colour-diagnostic objects (HCD, LCD) with typical colour (TC), atypical colour (AC) and unrelated adjective (UA) distractor in the three blocks in Experiment 1.

		TC	AC	UA
First block	HCD	0.16	0.19	0.17
	LCD	0.17	0.14	0.15
Second block	HCD	0.13	0.13	0.13
	LCD	0.10	0.10	0.11
Third block	HCD	0.11	0.12	0.12
	LCD	0.08	0.12	0.11

observed no semantic blocking interference on first presentations but only on later repetitions. This observation has also been reported by others using the cyclic blocking paradigm (Abdel Rahman & Melinger, 2007; Belke, Meyer, & Damian, 2005; Damian & Als, 2005). Recently, we investigated this issue combining cyclic blocking with a spatial frequency manipulation (different blurring levels of the pictures) and a visual similarity manipulation and found that for objects that are difficult to recognise (blurred pictures of objects from visually similar categories, e.g. birds) the semantic blocking effect is actually reversed on the first presentation of an object and enhanced on subsequent presentations (Scheibel & Indefrey, 2018). These findings suggest that naming latencies for the first presentation of an object are dominated by the time needed for recognition (and here homogeneous context helps), on subsequent presentations by the time needed for lexical selection (and here the competitors in the homogeneous context hinder). At least when presented early (400 ms before picture onset) congruent colour words thus seem to help object recognition.

In summary, the main goal of Experiment 1 was to follow up on one of the central open questions raised by Redmann et al. (2014): Could the lack of a facilitatory priming effect of a typical colour have been due to a mismatch between the colour presented before the picture and the representation in the object's frame? Our results support that this might have been the case: Experiment 1 showed that colour distractors presented as colour words 400 ms before target onset in fact facilitated naming of HCD objects. This result suggests that the lack of a similar congruency effect in the study reported by Redmann et al. (2014) could indeed be due to choosing a wrong colour distractor not corresponding to the representation of its typical colour in the object's frame. To further investigate the time-course of the congruency effect and the processing stages affected by it, a follow up study (Experiment 2) modulated the timing of distractor presentation.

3. Experiment 2

Experiment 2 was conducted to explore the time-course of semantic priming effects induced by typical colours in a PWI paradigm. To this aim, we varied SOA and presented the distractor before the picture (−200 ms), at the same time (SOA 0 ms), and after the picture (SOA +200 ms), thereby allowing a more complete picture of the dynamics of the colour congruency effect over time. As a further modification we included a second set of control stimuli, letter strings, because we reasoned that these stimuli should not activate lexical entries at all (as opposed to unrelated adjectives in the other control condition) Experiment 2 was conducted at Heinrich Heine University, Düsseldorf, Germany, and consequently used German native speakers instead of Dutch native speakers as in Experiment 1.

3.1. Design and objective

Like Experiment 1, Experiment 2 consisted of a PWI paradigm in which participants named a series of pictures of HCD and LCD objects. Each target picture was presented with a visual distractor in the form of a written German adjective. These distractors could refer to typical colours (*rote – tomate*; "red – tomato"), atypical colours (*braune – Tomate*; "brown – tomato"), unrelated adjectives (*leise – Tomate*; "quiet – tomato") or random letter strings (*nkfr – Tomate*; "nkfr – tomato"). To investigate the time course of congruency effects induced by colour distractors, we presented the distractors at three SOAs (−200 ms, 0 ms, +200 ms). By introducing the distractor at different time points in the process of naming the picture, it is possible to specifically target different processing stages that could be influenced by presentation of the distractor. Facilitation of typical colours at SOA −200 ms would suggest that colour priming already affects perceptual or conceptual stages in naming the target. Facilitation effects at SOA 0 ms would point to a later, lexical locus. Facilitation at an SOA of +200 ms would suggest an effect of colour priming at a processing stage later than lemma access. We expected that colour distractors should facilitate naming when presented at SOA −200 ms, SOA 0 ms, or both. We did not expect semantic effects to become effective at an SOA of +200 ms, since previous research has connected distractor presentation after the target picture to phonological rather than semantic processing (e.g., Jescheniak & Schriefers, 2001; Schriefers et al., 1990), and we did not manipulate phonological properties in the present study (see General

Discussion for details on our reasoning here). We also expected potential priming effects to only affect HCD objects (in line with the colour-diagnosticity hypothesis by Tanaka & Presnell, 1999). LCD objects should not benefit from co-activation of a colour adjective.

3.2. Methods

3.2.1. Participants

In total, 106 participants took part in the experiment (28 male and 78 female, mean age 23.51 years, $SD = 5.06$ years), which was conducted at Heinrich Heine University, Düsseldorf, Germany. Ten of these participants were recorded as replacements for participants excluded from further analysis due to high error rates (above 40% errors, 5 participants), not having followed the instructions (1 participant) or recording errors (4 participants). 96 participants (32 participants per SOA) were included in the final analysis. All participants were native speakers of German with normal or corrected-to-normal eyesight and no colour vision impairments and were paid for participation.

3.2.2. Materials

Since Experiment 2 was conducted with German-speaking participants, we constructed a new set of HCD and LCD items to make sure it was possible to match the target labels in German with respect to important linguistic features such as word length and frequency. Table 3 shows summary statistics for the 65 HCD and 65 LCD objects included as experimental items in the experiment.

The set of colours chosen as distractors included seven different German colour words: *braun* (brown), *grau* (grey), *gelb* (yellow), *grün* (green), *rot* (red), *schwarz* (black), and *weiß* (white). A set of seven adjectives for the unrelated adjective condition was chosen from CELEX (Baayen et al., 1993) to match log frequency, syllable and letter count of the colour distractor words (colour adjectives: mean log freq. 1.795, mean syllable count 1; unrelated adjectives: mean log freq. 1.86, mean syllable count 1.3). For the letter string condition, seven random letter strings were created (using the generator provided online by Dave Reed, http://www.dave-reed.com/randSeq.html) out of a set of consonants (phonotactically valid syllables were avoided in order to prevent participants from attempting lexical access), matched in terms of number of letters to the colour adjectives and the unrelated adjectives (mean: 5 letters ± 1.2 for all three distractor types).

Eight item groups were created, one for each experimental condition (HCD and LCD objects paired with a typical colour, atypical colour, unrelated adjective and letter string). Items were allocated to these eight groups in a way that ensured an equal number of items with a particular colour per group (but note that the number of items of a particular colour, e.g. typically red or green items, varied). These eight item groups were matched for log lemma frequency (using log frequency as provided by IPNP, Szekely et al., 2005), naming agreement, familiarity, difficulty of recognition, distribution of grammatical gender (i.e., approximately same number of female, male, neuter items), number of items starting with a fricative (since they can be difficult when determining VOTs), and number of syllables. Note that due to the nature of the colour-diagnosticity distinction (there are more natural HCD items than artificial ones), the number of natural items and number of animate items could not be equal in HCD and LCD conditions, but was kept as similar as possible across items assigned to the different distractor types (see Table 3). We created four experimental lists, such that every item appeared equally often in all experimental conditions across participants. To avoid carry-over and sequence effects, every list was split in two, so that each half of the list could be presented as the first part of the experiment to half of the participants, and as the second part of the experiment to the other half of the participants. All resulting lists were pseudo-randomised using the Shuffle software (Pallier, 2002), such that no more than two trials of the same condition could be next to each other, and that distractor words and target onset syllables were not repeated on subsequent trials. We included 208 filler items and combined them with colour adjectives and unrelated adjectives such that every unrelated adjective, colour adjective and letter string appeared the same number of times (16) during the whole experiment. Every colour adjective appeared approx. 50% of the time as congruent and incongruent with the target picture (± 1 trial). This selection procedure resulted in 96 unique experimental lists, 32 lists per SOA, such that every participant received a unique list.

3.2.3. Procedure

Target pictures were presented on a computer screen at a size of 240 × 240 pixel (with 1028 × 768 screen resolution). All pictures and text elements were presented in light blue on a dark blue background, so that the colours used on the screen were different from all colours used as distractors in the experiment. Distractors were placed centrally, except for when the distractor hid salient parts of the picture, in these cases (5 items) the distractor was moved slightly (but still in the central region of the picture). As in Experiment 1, stimulus presentation was controlled using the Presentation® software (Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). The experiment took place in a dimly lit, sound-proof cabin. Participants were instructed to name the pictures as fast and accurately as possible, and to ignore the distractor. Every trial started with a fixation cross (1000 ms) and a random interval between 0 and 200 ms in which a blank screen was shown. In the “SOA −200 ms” condition, the distractor appeared on the screen; after 200 ms, the picture appeared in the background, and distractor and picture remained on the screen for 2000 ms. In the “SOA 0 ms” condition, distractor and picture appeared at the same time and remained on screen for 2000 ms. In the “SOA +200 ms” condition, the picture appeared first, and after 200 ms, the distractor was presented on the picture. Picture and distractor remained on screen together for an additional 1800 ms. There was a 1000 ms intertrial interval. At the beginning of the experiment, there were 10 training trials, after which the participant could ask the experimenter any open questions. Evenly spaced throughout the experiment, there were five self-paced pauses. The experiment lasted approximately 20 min.

3.2.4. Data analysis

Reaction times were analysed using linear mixed models following the same procedure as for Experiment 1. The predictors used in the models were Colour-Diagnosticity (HCD, LCD), Distractor Type (typical colour, atypical colour, unrelated adjective, letter string), and SOA (−200 ms, 0 ms, +200 ms). Random error terms were defined following the same rationale as described for Experiment 1. In addition to the analysis including SOA as a predictor, separate analyses were conducted for the three different SOAs. Naming errors and trials with extremely long naming latencies were defined as described for Experiment 1 and excluded from further analyses (19.5%). Eight items (3 HCD; 5 LCD) were excluded due to high error rates (over 60%), mainly caused by the existence of synonyms (such as “Bohrer”/ ”Bohrmaschine”, “drill”), naming at the wrong level of specificity

Table 3
Summary statistics for matching factors between high and low colour-diagnostic (HCD, LCD) stimuli in Experiment 2.

	CD % (mean)	Word length (mean)	Log frequency (mean)	Familiarity (mean)	Difficulty of recognition (mean)	Natural objects (N)	All objects (N)
HCD	86.4	2.1	1.8	2.7	1.1	43	65
LCD	17.8	2.2	1.8	2.9	1.1	21	65

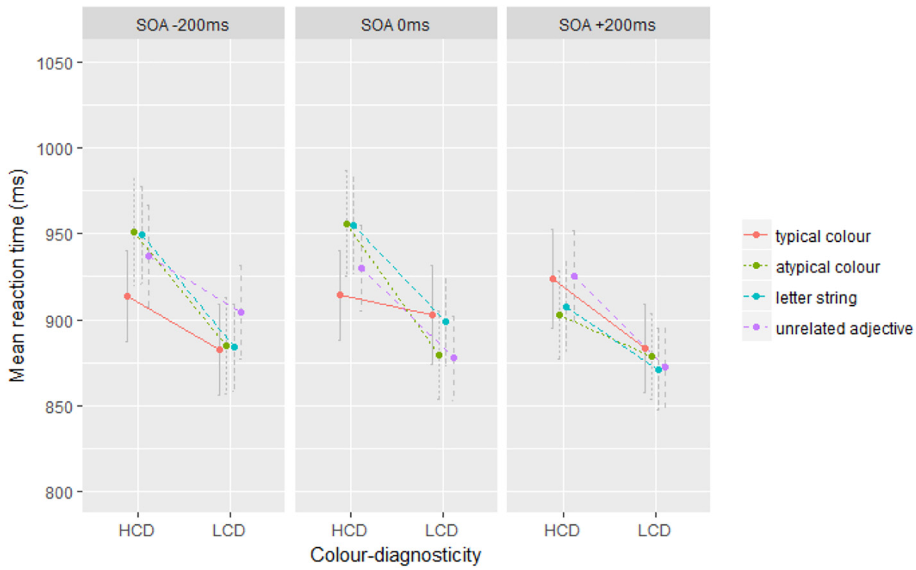

Fig. 3. Mean reaction times in ms for high and low colour-diagnostic objects (HCD, LCD) paired with typical colour, atypical colour, unrelated adjective distractor, or letter string for the three stimulus onset asynchronies (SOA, −200 ms, 0 ms, +200 ms) in Experiment 2. Error bars indicate 95% confidence intervals around the mean calculated using participants as id variable.

("Krankenschwester"/"Frau", "nurse"/"woman") or difficulty recognising the picture ("Pferdeschwanz", "ponytail").

3.3. Results

3.3.1. Reaction times

3.3.1.1. All SOAs. Mean reaction times at all SOAs are displayed in Fig. 3. When estimating linear mixed models in the overall analysis including all three SOAs, we included random intercepts for subject and item as well as by-subject slopes for Colour-Diagnosticity. Results were robust with other theoretically justified random error terms yielding converging model estimation.

The main effect of Colour-Diagnosticity did not reach significance ($\chi^2(1) = 3.653$, $p = 0.056$): SOA did not significantly affect reaction times ($\chi^2(2) = 1.070$, $p = 0.586$). We found no main effect of Distractor Type ($\chi^2(3) = 0.903$, $p = 0.823$), no interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(3) = 3.457$, $p = 0.326$), or between Colour-Diagnosticity, Distractor Type and SOA ($\chi^2(17) = 22.038$, $p = 0.1832$). To explore the specific predictions for the presence of congruency effects at the three different SOAs, we conducted further analyses for each SOA.[3]

3.3.1.2. SOA −200 ms. At SOA −200 ms, the analysis yielded no significant effect of Colour-Diagnosticity ($\chi^2(1) = 3.7421$, $p = 0.053$).[4] HCD objects were named more slowly than LCD objects by 48 ms. There was no effect of Distractor Type ($\chi^2(3) = 4.377$, $p = 0.224$). We found no significant interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(3) = 2.499$, $p = 0.475$), but the contrasts between HCD objects presented with a typical colour and HCD objects presented with an atypical colour ($t(3019.57) = -1.692$, $p = 0.045$) and a letter string ($t(3022.49) = -2.030$, $p = 0.021$) were significant. HCD objects with a typical colour distractor were named 37 ms faster than when presented with an atypical colour distractor, and 35 ms faster than when presented with a letter string. Naming latencies for LCD objects in the typical colour condition did not differ significantly from the atypical colour condition ($p = 0.56$) or the letter string condition ($p = 0.22$). All other contrasts and post-hoc comparisons were also non-significant.

3.3.1.3. SOA 0 ms. At SOA 0 ms, the main effect of Colour-Diagnosticity did not reach significance ($\chi^2(1) = 3.078$, $p = 0.079$). There was no effect of Distractor Type ($\chi^2(3) = 1.108$, $p = 0.775$). The interaction between Colour-Diagnosticity and Distractor Type did not reach significance ($\chi^2(3) = 7.695$, $p = 0.053$).[5] HCD objects were named significantly faster when paired with a typical colour as opposed to an atypical colour ($t(2992.46) = -2.013$, $p = 0.022$) and letter string ($t(2995.51) = -2.117$, $p = 0.017$). Planned contrasts between the two colour distractor conditions for LCD objects and all post-hoc comparisons did not reach significance.

3.3.1.4. SOA +200 ms. Again, the main effect of Colour-Diagnosticity did not reach significance at SOA + 200 ms ($\chi^2(1) = 2.8132$, $p = 0.093$). There was no significant interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(3) = 1.861$, $p = 0.602$). HCD objects were not named significantly faster when paired with their typical colour compared to an atypical colour, unrelated adjective or letter string as shown by contrasts (all $p > 0.05$). All other contrasts and post-hoc tests were non-significant.

3.3.2. Error rates

Naming errors were analysed using generalised linear mixed models following the procedure outlined for Experiment 1.

3.3.2.1. All SOAs. Generalised linear mixed models showed no main effect of Colour-Diagnosticity ($\chi^2(1) = 2.6223$, $p = 0.105$). However, the analysis yielded a main effect of SOA ($\chi^2(2) = 9.7053$, $p = 0.008$), post-hoc contrasts indicating that fewer errors were made at SOA +200 ms compared to SOA −200 ms ($z = -2.576$, $p = 0.030$) and SOA 0 ms ($z = -2.944$, $p = 0.010$). There was no main effect of Distractor Type ($\chi^2(3) = 1.788$, $p = 0.618$), but a significant interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(3) = 8.828$, $p = 0.032$), and a three-way interaction between Colour-Diagnosticity, Distractor Type and SOA ($\chi^2(17) = 28.122$, $p = 0.043$). To further explore this interaction, we turned to

[3] In the −200 ms and +200 ms condition, two participants were erroneously presented with distractors at −150 ms and +150 ms. Analyses with and without these participants showed the same overall results, with the following exception: At SOA −200 ms, the significant difference between HCD objects in the typical colour and atypical colour condition did not reach significance when the participants were excluded ($p = 0.07$).

[4] This effect was significant when also including a by-item random slope for Distractor Type ($\chi^2(1) = 3.883$, $p = 0.049$).

[5] This effect was significant when also including a by-subject random slope for Distractor Type ($\chi^2(1) = 7.979$, $p = 0.046$).

Table 4
Mean error rates for high and low colour-diagnostic objects (HCD, LCD) with typical colour (TC), atypical colour (AC), unrelated adjective (UA) and letter string (LS) distractor using three different stimulus onset asynchronies (SOA) in Experiment 2.

		TC	AC	UA	LS
SOA −200 ms	HCD	0.17	0.21	0.21	0.18
	LCD	0.15	0.14	0.13	0.16
SOA 0 ms	HCD	0.18	0.19	0.20	0.21
	LCD	0.19	0.18	0.17	0.13
SOA +200 ms	HCD	0.17	0.14	0.17	0.14
	LCD	0.14	0.11	0.10	0.11

subanalyses per SOA to systematically examine the effects of interest.

3.3.2.2. SOA −200 ms. At this SOA, a simplified random effects structure was used compared to the other SOAs: Since inclusion of random by-subject slopes for Colour-Diagnosticity lead to non-convergence of the models, we included only random intercepts for subjects and items. We found no significant main effect of Colour-Diagnosticity ($\chi^2(1) = 2.676$, $p = 0.102$) or Distractor Type ($\chi^2(3) = 2.396$, $p = 0.494$). The interaction between Colour-Diagnosticity and Distractor Type did not reach significance ($\chi^2(3) = 7.188$, $p = 0.066$). Contrasts revealed that fewer errors were made for HCD objects presented with a typical colour distractor than with an atypical colour distractor ($z = -2.267$, $p = 0.012$) or an unrelated adjective ($z = -2.144$, $p = 0.016$), whereas all other contrasts and post-hoc comparisons were non-significant, see Table 4 for mean error rates).

3.3.2.3. SOA 0 ms. There was no significant main effect of Colour-Diagnosticity at SOA 0 ms ($\chi^2(1) = 1.048$, $p = 0.306$) or Distractor Type ($\chi^2(1) = 1.666$, $p = 0.645$). The interaction between Colour-Diagnosticity and Distractor Type did not reach significance ($\chi^2(3) = 7.315$, $p = 0.062$). Planned contrasts and post-hoc comparisons were non-significant.

3.3.2.4. SOA +200 ms. As in the reaction time analysis, the main effect of Colour-Diagnosticity effect at SOA + 200 did not reach significance ($\chi^2(1) = 2.744$, $p = 0.098$). No main effect of Distractor Type ($\chi^2(3) = 6.139$, $p = 0.105$) and no interaction between Colour-Diagnosticity and Distractor Type ($\chi^2(3) = 4.153$, $p = 0.245$) were found. Planned contrasts and post-hoc comparisons did not reach significance.

3.4. Discussion

Our results again showed a congruency effect: When presenting a typical colour as a distractor for HCD objects, activation of the colour facilitated naming that object compared to an atypical colour distractor. This congruency effect was found when presenting the distractor 200 ms before the target picture, or at the same time as the target picture. These results are in line with previous research showing facilitation from distractors that are parts of the target or associatively related with the target (Alario et al., 2000; Costa et al., 2005; Sailor & Brooks, 2014). Congruent colour distractors also showed a priming effect when compared to a neutral control stimulus (a random letter string). No such congruency or priming effects were found when presenting the distractor after target picture onset (with an SOA of 200 ms). In line with the colour-diagnosticity hypothesis by Tanaka and Presnell (1999), the effect was only found for HCD objects, whereas LCD objects did not benefit from colour distractors.

In accordance with results from Experiment 1, HCD objects were named more slowly across all SOAs. However, this effect did not reach significance in Experiment 2, which might be attributed to the influence of the congruent colour condition in the case of HCD objects (cf. Fig. 3).

In summary, our results from Experiment 2 show that (pre-)activation of typical colour attributes affects naming of HCD target words, when presented at a negative SOA or simultaneously with the target picture. Furthermore, the colour congruency effect found in Experiment 2 suggests that the effect is not only present in native speakers of Dutch, but that it is generalisable to native speakers of German. Theoretical implications of our findings with respect to the locus of the colour congruency effect will be discussed below.

4. General discussion

4.1. Colour-diagnosticity

In line with earlier findings, our results provided evidence for a colour-diagnosticity effect: HCD objects were consistently named more slowly than LCD objects. This finding is in accordance with results from the literature (e.g., Bramão et al., 2010; Redmann et al., 2014; Tanaka & Presnell, 1999; Therriault et al., 2009). A possible reason for this detrimental effect of high colour-diagnosticity on naming lies in the fact that HCD objects tend to be structurally more similar to each other than LCD objects: Different kinds of fruit or vegetables, which are often colour-diagnostic to a high degree, are more similar in shape than, for instance, different tools or vehicles, which are mostly LCD (Laws & Hunter, 2006; Tanaka & Presnell, 1999). Because of this tendency, LCD objects can be identified more readily based on shape information alone, as was required in the present task, where the objects were presented as achromatic line drawings. For HCD objects, discrimination from other HCD objects based on shape information alone is more effortful (e.g., telling an achromatic orange from an achromatic tomato). As proposed by Laws and Hunter (2006), colour information might help shape segmentation, meaning that a lack of colour information prolongs this process in recognising the object (see also Bramão, Reis, Petersson, & Faísca, 2016; Gegenfurtner & Rieger, 2000).

4.2. Congruency effect

A colour congruency effect was found when presenting the distractor 400 ms (Exp.1) or 200 ms (Exp.2) before the target picture, or at the same time as the target picture (Exp.2): HCD objects were named faster when preceded by a colour word denoting their typical colour (e.g., *red - tomato*) compared to an atypical colour (e.g., *brown - tomato*). This finding is in line with studies using a PWI paradigm showing facilitatory effects of distractors that are parts of the target (*bumper - car*) or associatively related to the target (*carrot - rabbit*) at negative SOAs and SOA 0 ms (e.g., Bölte et al., 2003; Costa et al., 2005; Hirschfeld et al., 2008; Jorschick et al., 2005; Muehlhaus et al., 2013; Sailor et al., 2009; Sailor & Brooks, 2014). Congruent colour distractors also showed a priming effect when compared to a neutral control stimulus (a letter string) for HCD objects. We found no significant difference between congruent colour distractors and unrelated adjectives. In both experiments, HCD objects with unrelated adjectives were named faster than HCD objects with incongruent colour distractors, and slower than HCD objects with congruent colour distractors (although none of these differences were statistically significant). This pattern might suggest that the colour congruency effect could be the net result of a) facilitation when paired with a congruent colour and b) inhibition when paired with an incongruent colour.

The congruency effect found here contrasts with our results from Redmann et al. (2014), where we used coloured boxes as distractors, and did not find any behavioural differences as a function of distractor type (typical colour vs. black and white checkerboard pattern). The presence of a behavioural congruency effect in the current study is consistent with the hypothesis that in Redmann et al. (2014), a shade of colour was chosen as a distractor that did not fully correspond to the colour represented as a value of the colour attribute in the object's frame, and thus failed to prime the object's colour feature at a conceptual level. Activating a wider range of colours by means of a colour word produced the expected facilitatory effect, suggesting the colour attribute could be pre-activated via the colour word and in turn boost activation of the target concept, and subsequently, the target lemma. This mechanism has been described by, among others, Abdel Rahman and Melinger (2009b), and is compatible with both competitive and non-competitive accounts of lexical access (cf. Geng, Kirchgessner, & Schnur, 2013; Mädebach, Kieseler, & Jescheniak, 2017).

An alternative explanation for the presence of a colour congruency effect with verbal primes and its absence with colour box primes was suggested by one reviewer: There is neuropsychological evidence that object colour knowledge representations consist of two distinct codes, a visual and a verbal code (Tanaka, Weiskopf, & Williams, 2001; for studies supporting this distinction see Beauvois & Saillant, 1985, and Hart Jr & Gordon, 1992), the latter having a stronger influence on object naming (Zannino et al., 2010). Colour words (as used as distractors in Experiment 1 and 2) and visual colour perception (as the colour boxes employed as distractors in Redmann et al., 2014) might thus contribute differently to the process of recognising and naming an object. Specifically, colour words might activate the verbal colour code more strongly than colour boxes, which could strengthen the colour congruency effect. We agree that such a dual code account could in principle explain our findings, if it can be shown that (a) also in non-clinical populations verbal colour labels have a stronger impact on object naming than the visual colours themselves and that (b) activation of the verbal code upon seeing colour boxes such as those used as distractors in Redmann et al. (2014) is too weak or too late to cause any priming effect. These issues need to be addressed in future research.

4.3. Theoretical implications

4.3.1. The locus of the congruency effect

There is an ongoing debate on the locus of interference effect in PWI; some authors attribute these effects to the lexical level (e.g., Piai et al., 2012), others have situated them at earlier, prelexical stages of processing (e.g., Dell'Acqua, Job, Peressotti, & Pascali, 2007; van Maanen, van Rijn, & Borst, 2009). With respect to facilitatory effects, like the congruency effect found in the present study, there is electrophysiological evidence locating them at perceptual stages of object identification (Hirschfeld et al., 2008), or at both conceptual and lexical processing stages (Aristei et al., 2011). Both studies will be outlined in the following, since they give some indication as to the processing stage at which the effect might exert its influence. First, there is electrophysiological evidence for an early, perceptual locus of facilitation induced by surface features: Hirschfeld et al. (2008) found an effect of surface features in a PWI paradigm compared to category members and unrelated words in the 120-220 ms time window. According to Piai et al. (2012), picture-shape processing takes place in a similar time frame (at ca. 100–200 ms). In accordance with this assumption, Hirschfeld et al. (2008) interpret the effect in this time window as evidence for surface features exerting a top-down influence on visual object perception. Given the strong evidence that colour helps recognition of HCD objects (cf. Bramão et al., 2011), it would be reasonable to assume that in the present study, the activation of typical colours might influence processing of the target objects at this stage as well.

Aristei et al. (2011) used PWI in a semantic blocking paradigm, where blocks of either associatively related (homogeneous blocks) or unrelated pictures (heterogeneous blocks) were shown. These pictures were superimposed with distractor words that were either associatively related or unrelated. As expected, they observed semantic facilitation from associates in heterogeneous blocks. In homogeneous blocks, they observed interference from associates, which they attribute to the activation of a lexical cohort. They found ERP effects as a function of both associative and semantic relatedness in the time window between 200 and 300 ms. The authors conclude that the two effects are either located at the same or highly interactive processing stages, namely, conceptual processing (identifying the object as an instance of its basic-level category, e.g., a tomato) and lexical access (see also Bloem, 2003; Levelt, Roelofs, & Meyer, 1999). This is compatible with our findings that the congruency effect was present when the distractor was presented before the picture (at SOA −400 ms and −200 ms), and when it was presented at the same time (SOA 0 ms).

Our results could suggest that activation of the colour attribute influences production of the target word at the perceptual level, the conceptual level and/or the lexical level. None of these possibilities can be excluded based on the present data. First, it is conceivable that the colour distractor helps object recognition, particularly in the case of HCD objects, whose recognition has been shown to be adversely affected by presentation in black and white (e.g., Redmann et al., 2014; Therriault et al., 2009). Second, it is possible that the colour distractor exerts its influence at the conceptual level, where activation of the target concept is strengthened via its colour attribute. Third, there might be a direct connection from the colour to the lemma level, restricting the search space of possible lemmata to refer to the target concept.

In contrast, the results from Experiment 1 and 2 suggest that we can rule out an effect of activating the colour attribute on naming colour-diagnostic objects at processing stages later than lemma access, since we found no evidence for a congruency effect when presenting the colour distractor 200 ms after the target picture. This finding is in line with previous research indicating that distractors presented after the target picture influence naming only when there is a relation to the target picture in terms of phonology (e.g., Jescheniak & Schriefers, 2001; Schriefers et al., 1990), whereas distractors in the current experiment were semantically related to the target picture (their phonological properties were matched rather than manipulated as independent variable). Furthermore, since there were no forward-associations between the colour distractors and the concepts denoted by the target pictures, a priming effect based purely on connections between word forms can be excluded. We can also exclude explanations on the basis of response relevance of the distractor, since no condition in the present experiments included distractors that would constitute possible naming responses: All distractors were adjectives whereas target pictures had to be referred to with nouns.

In summary, our results from Experiments 1 and 2 provide support for both a pre-lexical and lexical locus of the congruency effect. They rule out the possibility that the effect only starts later than lemma access.

4.3.2. Consequences for frame-theory

Our findings of a colour congruency effect have implications for frame theory concerning the role and structure of colour attributes: They support the notion that the colour attribute is represented differently for HCD objects than for LCD objects. As suggested by Petersen (2007), this difference could lie in the underspecification of the colour attribute in the case of LCD objects ([*colour*: colour] in the frame of *skirt*), whereas HCD objects have one or more colours specified ([*colour*: red] in the frame of *tomato*). Alternatively, both HCD and LCD objects could have an attribute-value pair [*colour*: colour] with further attributes such as *hue*, *saturation* and *brightness*, which are underspecified for LCD objects. Our present results support the notion that the degree of specification of either a) the colour attribute or b) sub-attributes further describing the colour of the object is a difference between frames of HCD and LCD objects, and that this difference in representation can be observed in human behaviour (colour-diagnosticity effect). How exactly possible and prototypical colours are specified for HCD objects has not yet been fully formalised. Further experimental evidence is needed to explore, for instance, which attributes are attached to these colour nodes (e.g., hue, saturation, and brightness), or how ranges of colours in colour space can be specified as possible surface colours of the object.

5. Conclusion

The current study investigated the time course of colour congruency effects in two reaction time experiments using the picture-word interference paradigm with different SOAs (Exp. 1: -400 ms, Exp. 2: −200 ms, 0 ms, and +200 ms). The results revealed a colour congruency effect showing facilitation by typical colours compared to atypical colours for HCD objects when the distractor preceded the target picture or when they were presented at the same time. Activation of the colour attribute did not activate low colour-diagnostic objects. Our findings confirm previous results showing that colour information influences naming of objects only when they are connected to a typical colour (HCD objects). They also suggest that colour representations for HCD objects are specific rather than general. Further, the results speak for a pre-lexical or lexical locus of the colour congruency effect, while ruling out a possible locus at a processing stage later than lemma access.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A. Appendix

A.1. Items and distractors used in Experiment 1

List of high and low colour-diagnostic experimental items in Experiment 1 (English translation in brackets).

High colour-diagnostic objects	aardappel (potato), aardbei (strawberry), ananas (pineapple), anker (anchor), banaan (banana), beer (bear), bom (bomb), bot (bone), boter (butter), brood (bread), bruid (bride), cactus (cactus), citroen (lemon), deegroller (rolling pin), dennenappel (pine cone), dolfijn (dolphin), dromedaris (dromedary), egel (hedgehog), ei (egg), eikel (acorn), eland (moose), haai (shark), hert (deer), iglo (igloo), ijsbeer (polar bear), kaas (cheese), kameel (camel), kangoeroe (kangaroo), kers (cherry), kikker (frog), kreeft (lobster), krokodil (crocodile), kroon (crown), kurk (cork), lepel (spoon), mammoet (mammoth), mes (knife), mier (ant), muis (mouse), neushoorn (rhino), nijlpaard (hippopotamus), olifant (elephant), peer (pear), pinda (peanut), piramide (pyramid), plank (shelf), pleister (band aid), pompoen (pumpkin), saxofoon (saxophone), schaap (sheep), schildpad (turtle), schroef (screw), skelet (skeleton), sneeuwpop (snowman), spaghetti (spaghetti), spijker (nail), spin (spin), spook (ghost), tak (branch), tand (tooth), tank (tank), tomaat (tomato), ton (barrel), touw (rope), trompet (trumpet), viool (violin), vleermuis (bat), vlieg (fly), vork (fork), vuur (fire), wasmachine (washing machine), wortel (carrot), zadel (saddle), zon (sun), zwaan (swan)
Low colour-diagnostic objects	accordeon (accordion), asbak (ashtray), bal. (ball), balkon (balcony), ballon (balloon), bh (bra), bloem (flower), bril (glasses), broodrooster (toaster), cadeau (present), dinosaurus (dinosaur), draak (dragon), emmer (bucket), fluit (whistle), glijbaan (slide), haak (hook), hak (heel), helicopter (helicopter), helm (helmet), hengel (fishing rod), hoed (hat), horloge (watch), jurk (dress), kaars (candle), kam (comb), kasteel (castle), kat (cat), ketting (chain), kinderwagen (stroller), klok (clock), knoop (button), kompas (compass), ladder (ladder), lamp (lamp), liniaal (ruler), masker (mask), mixer (mixer), muts (hat), octopus (octopus), papegaai (parrot), paraplu (umbrella), pen (pen), pijl (arrow), poot (leg), riem (belt), rietje (straw), rok (skirt), schelp (shell), schommel (swing), sjaal (scarf), slak (snail), slang (snake), sok (sock), stekker (plug), stempel (stamp), strik (bow), stropdas (tie), taart (cake), tandenborstel (toothbrush), tuinslang (hose), tulp (tulip), typemachine (typewriter), vaas (vase), veer (feather), vingerhoed (thimble), vis (fish), vlag (flag), vleugel (wing), vlieger (kite), vlinder (butterfly), vrachtwagen (truck), waaier (fan), wasknijper (clothespin), weegschaal (scale), zeepaard (seahorse)

List of distractor words in Experiment 1 (English translation in parentheses).

colours	bruin (brown), geel (yellow), gouden (gold), grijs (grey), groen (green), oranje (orange), rood (red), wit (white), zilveren (silver), zwart (black)
unrelated adjectives	bitter (bitter), fris (fresh), jong (young), kalm (calm), langzaam (slow), luid (loud), nerveus (nervous), opgelucht (relieved), zacht (quiet), zout (salty)

A.2. Items and distractors used in Experiment 2

List of high and low colour-diagnostic experimental items in Experiment 2 (English translation in parentheses).

High colour-diagnostic objects	Amboss (anvil), Ameise (ant), Ananas (pineapple), Anker (anchor), Ast (branch), Badewanne (bathtub), Banane (banana), Biene (bee), Birne (pear), Bombe (bomb), Braut (bride), Delphin (dolphin), Ei (egg), Eichel (acorn), Elch (moose), Erdbeere (strawberry), Erdnuss (peanut), Esel (donkey), Fass (barrel), Feuer (fire), Feuerwehr (fire truck), Fledermaus (bat), Fliege (fly), Frosch (frog), Fuchs (fox), Geige (violin), Gespenst (ghost), Hai (shark), Heuschrecke (grasshopper), Hirsch (deer), Hummer (lobster), Iglu (igloo), Kaenguruh (kangaroo), Kaese (cheese), Kaktus (cactus), Kamel (camel), Kirsche (cherry), Knochen (bone), Krankenschwester (nurse), Krokodil (crocodile), Loewe (lion), Mais (corn), Mund (mouth), Mutter (mother), Nagel (nail), Nashorn (rhino), Nilpferd (hippo), Nudelholz (rolling pin), Panzer (tank), Pflaster (bandaid), Pyramide (pyramid), Reifen (tire), Sattel (saddle), Schaf (sheep), Schildkroete (turtle), Schraube (screw), Schwan (swan), Seil (rope), Skelett (skeleton), Spaghetti (spaghetti), Toilette (toilet), Tomate (tomato), Walnuss (walnut), Zwiebel (onion)
Low colour-diagnostic objects	Akkordeon (accordion), Angel (fishing rod), Aschenbecher (ashtray), Balkon (balcony), Bank (bank), Bart (beard), Blume (flower), Bohrmaschine (drill), Boot (boat), Brille (glasses), Buerste (brush), Dinosaurier (dinosaur), Drache (dragon), Eimer (bucket), Eis (ice cream), Fahne (flag), Feder (feather), Fernglas (binoculars), Fingerhut (thimble), Fisch (fish), Fluegel (wing), Geschenk (present), Guertel (belt), Hase (rabbit), Helm (helmet), Hubschrauber (helicopter), Hund (dog), Jacke (jacket), Jo-Jo (yoyo), Kaefer (beetle), Kamm (comb), Kerze (candle), Kinderwagen (stroller), Klammer (clip), Kleid (dress), Kleiderbuegel (hanger), Knopf (button), Kommode (dresser), Krake (octopus), Leiter (ladder), Lineal (ruler), Lkw (truck), Maske (mask), Motorrad (motorcycle), Muetze (hat), Muschel (shell), Papagei (parrot), Pfeil (arrow), Pferd (horse), Pferdeschwanz (ponytail), Pfote (paw), Rucksack

	(backpack), Rutsche (slide), Schal (scarf), Schaukelstuhl (rocking chair), Schlange (snake), Schmetterling (butterfly), Schnecke (slug), Schreibmaschine (typewriter), Seepferdchen (sea horse), Staubsauger (vacuum cleaner), Vogel (bird), Waage (scale), Zelt (tent)

List of distractor words in Experiments 2 (English translation in parentheses).

Colours	braun (brown), grau (grey), gelb (yellow), grün (green), rot (red), schwarz (black), weiß (white)
Unrelated adjectives	steil (steep), leise (quiet), leer (empty), laut (loud), langsam (slow), tief (deep), schnell (fast)

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