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Colour in concepts

Accessing conceptual components in language production

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Abstract

The present dissertation investigates the activation of conceptual components during language production, focusing on the role of object colour. The first chapter provides a short general introduction to the topic. The second chapter introduces the theoretical basis for the following empirical studies. It provides an overview over theories of conceptual presentation (focusing on frame theory) and the role of colour in object recognition and naming. Furthermore, it introduces the model of language production adopted in the present thesis, and the behavioural and electrophysiological methods employed in the reported experiments. The third chapter outlines a previous electrophysiological study, which acts as a point of departure for the empirical studies reported in the present thesis.

The empirical part of the thesis consists in a series of four experiments investigating effects of pre-activation of the colour attribute on language production. In a picture-word interference paradigm, objects were presented in the context of typical colours, atypical colours, unrelated adjectives and random letter strings. The objects presented in the experiments were either associated with a typical colour (such as bananas), or not closely connected to any typical colour (e.g., bicycles). The results showed that (pre-)activation of the colour attribute facilitated naming. This was only the case for objects closely associated with a typical colour, whereas activation of the colour attribute did not have an influence on naming objects that were not associated with a typical colour. Additional analyses of the behavioural data revealed that this effect was modulated by the degree to which the to-be-named object was associated with its typical colour. Our analyses also showed that the interpretation of a specific electrophysiological signature, the P2

component, as an index of difficulty of accessing an object's name (Costa, Strijkers, Martin, & Thierry, 2009; Strijkers, Costa, & Thierry, 2010) should be reconsidered.

The last chapter provides a general discussion of the behavioural and electrophysiological results, and interprets them in terms of their theoretical consequences for frame theory and their implications for methods in the study of language production.

Zusammenfassung

Die vorliegende Dissertation untersucht die Aktivierung konzeptueller Komponenten in der Sprachproduktion unter besonderer Berücksichtigung von Farbeigenschaften. Das erste Kapitel enthält eine kurze allgemeine thematische Einführung. Das zweite Kapitel bettet die Arbeit in ihren theoretischen Hintergrund ein. Es stellt zum einen Theorien zur mentalen Repräsentation von Konzepten (insbesondere durch *frame theory*) vor, und umreißt zum anderen den bisherigen Forschungsstand zur Rolle von Farbaktivierungen in Objekterkennung und -benennung. Weiterhin führt es in das der Arbeit zugrundeliegende Modell der Sprachproduktion ein und stellt zentrale behaviorale und elektrophysiologische Methoden vor, die im empirischen Teil der Arbeit Anwendung fanden. Das dritte Kapitel beschreibt eine elektrophysiologische Studie, die den Ausgangspunkt der in dieser Arbeit berichteten Experimente bildet.

Der empirische Teil der Arbeit besteht aus einer Serie von vier Experimenten, die die Auswirkungen einer Prä-Aktivierung von Farbattributen auf Sprachproduktionsprozesse untersuchen. Dabei wurden Objekte in einem Bild-Wort-Interferenz-Paradigma im Kontext von typischen Farben, atypischen Farben, unrelatierten Adjektiven und zufälligen Buchstabenfolgen präsentiert. Die gezeigten Objekte waren entweder mit einer typischen Farbe assoziiert (wie z.B. Bananen), oder mit keiner typischen Farbe verbunden (z.B. Fahrräder). Die Ergebnisse zeigten, dass (Prä-)Aktivierung des Farbattributes die Objektbenennung vereinfachte. Nur solche Objekte waren von dieser Vereinfachung betroffen, die über eine typische Farbe verfügten, während die Aktivierung des Farbattributs keine Auswirkung auf Objekte hatte, die nicht mit einer typischen Farbe assoziiert waren. Zusätzliche Analysen zeigten, dass dieser Effekt durch den Grad der Assoziation eines zu benennenden Objekts mit seiner typischen Farbe

moduliert wurde. Weiterhin zeigten unsere Analysen, dass die Interpretation einer spezifischen elektrophysiologischen Signatur, der P2-Komponente, als einem Indikator für den Grad der Schwierigkeit des Zugriffs auf den Namen eines Objektes (Costa et al., 2009; Strijkers et al., 2010) überdacht werden sollte.

Das letzte Kapitel bietet eine allgemeine Diskussion der behavioralen und elektrophysiologischen Ergebnisse und interpretiert sie in Hinblick auf theoretische Schlussfolgerungen für *frame theory*, sowie ihre Implikationen für Methoden in der Sprachproduktionsforschung.

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As I have learned over the past few years, the concept of a doctoral thesis could not be complete without the people who helped it come into existence: my supervisors, co-workers, friends and family. I would like to whole-heartedly thank all of you for your support.

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List of abbreviations

EEG	Electroencephalography
ERPs	Event-related potentials
HCD	high colour-diagnostic
ISI	Interstimulus interval
ITI	Inter trial interval
LCD	low colour-diagnostic
M	Mean
PWI	Picture-word interference
RT	Reaction times
SD	Standard deviation
SE	Standard error of the mean
SIE	Semantic interference effect
SOA	Stimulus onset asynchrony

1 Introduction

"[O]ver the wine-dark sea."

(Homer, trans. 1988; cf. Alexander, 2013)

The famous quotation by Homer referring to the sea as having a "wine-dark" colour has sparked discussion and controversy in studies of literature and philology over hundreds of years. Why does it strike the contemporary reader as surprising that the Ancient Greek philosopher chose to describe the sea as wine-coloured, that is, presumably of a dark red colour? It is because of a mismatch with the information we have stored in long-term memory about what the sea typically looks like and which colours it can have (probably blue or green, but not red). How we mentally represent pieces of information such as these about the world we live in, how we learn and form memories, and how we use these conceptual representations in communication has been a subject of study and debate for a long time (for an overview, see Murphy, 2004).

To answer these questions, some authors have proposed decompositional models of conceptual representations (Bierwisch & Schreuder, 1992; Goldman, 1975). According to these models, concepts (e.g., the concept of a tomato) consist of sets of features (e.g., *red* or *round*), and there is no abstract representation of the concept as a whole (e.g., TOMATO). Non-decompositional accounts, on the other hand, do assume a central conceptual node such as TOMATO, which is connected to other conceptual nodes such as RED or ROUND via different conceptual relations. Importantly, these two lines of theories have different implications for accessing the word used to refer to a concept in language production. This process is referred to as lexical access (Levelt, Roelofs, & Meyer, 1999). Decompositional accounts assume that the word referring to the object denoted by the concept (e.g., the word "tomato") is directly accessed by its conceptual features (e.g., *round*), and not by a unitary node (e.g., TOMATO). In contrast, non-decompositional accounts posit that there is such an abstract representation of the concept, and only this node (e.g., TOMATO) can be used to access the word referring to the concept stored in the mental lexicon, whereas conceptual features do not have direct access to the object's name.

Whether concepts can be best represented in a decompositional or non-decompositional way has repercussions for theories modelling conceptual representations as frames. The notion of conceptual representations employed in the present dissertation is based on frames as proposed by Barsalou (Barsalou, 1992; Gamerschlag, Gerland, Osswald, & Petersen, 2015). From a frame-theoretical point of view, a concept is represented by a central node (e.g., TOMATO) and recursive attribute-value structures further specifying the concept (e.g. [**shape**: ROUND]).

The present dissertation aims to explore the way in which attributes and values are stored in frames, and how words for concepts are accessed during language production. Specifically, it aims to investigate whether and how the activation of an attribute within a frame might influence lexical access to the concept's name. To do so, the thesis focuses on a single attribute present in frames of concrete objects: surface colour.

With respect to colour attributes, previous research has provided evidence that colour plays a different role in naming objects that have a typical colour (high colour-diagnostic objects such as banana) than for objects with no typical colour (low colour-diagnostic objects such as bicycle; for a review, see Bramão, Reis, Petersson, & Faísca, 2011). For instance, the naming of high colour-diagnostic objects is facilitated when the object is correctly coloured as opposed to when it is presented in an atypical colour or in black and white, whereas low colour-diagnostic objects do not seem to benefit from the additional colour information as much as high colour-diagnostic objects (Price & Humphreys, 1989; Therriault, Yaxley, & Zwaan, 2009; Redmann, FitzPatrick, Hellwig, & Indefrey, 2014, Exp.

1; for a meta-analysis see Bramão, Reis et al., 2011; but see Biederman & Ju, 1988 and Davidoff & Ostergaard, 1988, who did not find an effect of surface colour on object recognition).

Based on these previous findings, we used behavioural and electrophysiological methods to investigate potential effects of an object's typical colour in a paradigm that has been widely employed to study language production processes, the picture-word interference paradigm (Schriefers, Meyer, & Levelt, 1990). In this paradigm, participants name pictures of objects, which are presented in the context of words that are related to the object (e.g., a picture of a cat superimposed with the word "dog"). This paradigm was used to investigate whether naming is facilitated when typical colours are presented alongside the picture (e.g., red superimposed on the picture of a tomato) compared to atypical colours (such as brown), unrelated adjectives (such as quiet), or random letter strings. To further explore the time course of these potential effects, distractor words were presented at different time points relative to the to-be-named picture (-400ms, -200ms, 0ms, and +200ms). 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 present thesis is structured in the following way: Chapter 2 gives an overview over the theoretical background and literature that the empirical studies in the present dissertation were based on, and motivates the use of the psycho- and neurolinguistics methods employed in these studies. Chapter 3 presents a previously published experiment, which acts as a starting point for the main research questions followed up on in the empirical studies. Chapters 4 to 7 present and discuss a series of behavioural and electrophysiological studies that were used to investigate the central research questions (Experiments 1 to 4). Chapter 8 describes an additional correlation analysis performed on the reaction time data obtained in Experiments 1 to 4, that further clarify the behavioural result pattern found in these studies. Finally, Chapter 9 summarises and discusses the findings of the present dissertation in terms of theoretical and methodological consequences, and gives an outline of possible future research on the representation of and access to colour attributes in frames.

2 Theoretical background

This chapter will provide an overview on theories of conceptual representations (Chapter 2.1) focusing on frame theory. Chapter 2.2 describes a widely adopted model of language production. Chapter 2.3 introduces previous research on the role of colour in object recognition and, crucially, language production. Chapters 2.4 and 2.5 will introduce the behavioural and electrophysiological methods employed in Experiments 1 to 4 and motivate their use.

2.1 Conceptual representations

Models of conceptual representations generally take the form of either decompositional (e.g., Goldman, 1975; Jackendoff, 1995; Bierwisch & Schreuder, 1992) or non-decompositional frameworks (e.g., Collins & Loftus, 1975; Roelofs, 1992, 1993, 1997a; Levelt et al., 1999). Following decompositional accounts, concepts consist of sets of conceptual features, the collection of which makes up the concept. For instance, the concept for TOMATO[1] would consist of a set of features such as *red*(x), *round*(x), and *edible*(x). The combination of these features is then considered the concept, whereas no abstract representation of the concept as a whole, *tomato*(x), is needed. Non-decompositional accounts, on the other hand, assume that a concept is represented by a central, indivisible conceptual node ("chunk"), which is connected to other conceptual nodes via semantic links. These other nodes may correspond to semantic features of the concept (such as *edible*(x)), but they are not contained in the chunk *tomato*(x) as proper parts (Roelofs, 2002). Crucially, whether concepts are represented in a decompositional

[1] Here and in the following, „concept" is intended to mean categorical concepts, not instances (i.e., referring to the category of cats, not a specific exemplar). Features of a concept are assumed to generalize (to a varying degree) across instances of this category. For instance, most cats have fur, so fur would be included as a feature (Kiefer and Pulvermüller, 2012). For a discussion on individual frames, see Petersen and Werning (2007).

or non-decompositional manner has repercussions for theories of conceptual representation as well as processes involved in speech production (see Dell, 1986; Finkbeiner & Caramazza, 2006; Levelt et al., 1999; Roelofs, 1993).

The present dissertation focuses on frame-based representation as proposed by Barsalou (e.g., Barsalou, 1992, 2008; Barsalou, Simmons, Barbey, & Wilson, 2003) and as further developed by the CRC991 (Gamerschlag et al., 2015; Löbner, 2014; Petersen, 2007). By investigating access mechanisms to conceptual components in language production, it aims to inform frame theory as to whether access to an objects name can be assumed to happen in a non-decompositional or decompositional manner.

2.1.1 Frame-based representations

Barsalou (1992) proposed frames, in the form of recursive attribute-value structures, as the general format of conceptual representations. Originating in the field of artificial intelligence (Brachman & Schmolze, 1989; Minsky, 1974), the notion of conceptual frames has since entered other fields such as psychology, linguistics, and philosophy, and has become a widely-used tool in the study of (e.g., mental) representations. Attributes within frames assign properties to the object described by the frame, whereas values further specify properties (cf. attribute-value pairs such as [*form*: **round**] for the concept of ball). They do so in a functional manner: An attribute assigns a unique value to an object denoted by the frame. Values can be concrete (such as [*wheels*: **four**] in the frame of car) or underspecified (such as [*duration*: **duration**] in the frame of vacation; Petersen, 2007). Frames are recursive in the sense that these values can be further specified by attributes to an arbitrary level of detail. They can be enriched by constraints between values of different attributes. For instance, there could be a constraint between "duration" and “velocity” in the frame for “transport” (Barsalou, 1992), they cannot be changed independently of each other.

Frames can be represented as directed graphs (Barsalou, 1992; Petersen, 2007).[2] The present dissertation will follow notation conventions as proposed by Petersen (2007). She models frames as connected directed graphs, which include labelled nodes (indicating values or types) and labelled arcs (indicating attributes). Attribute arcs point to their respective values. The central node referring to the concept described by the frame is marked by a double circle as in Figure 2-1 (for a formal definition, see Petersen, 2007, *p*.5).

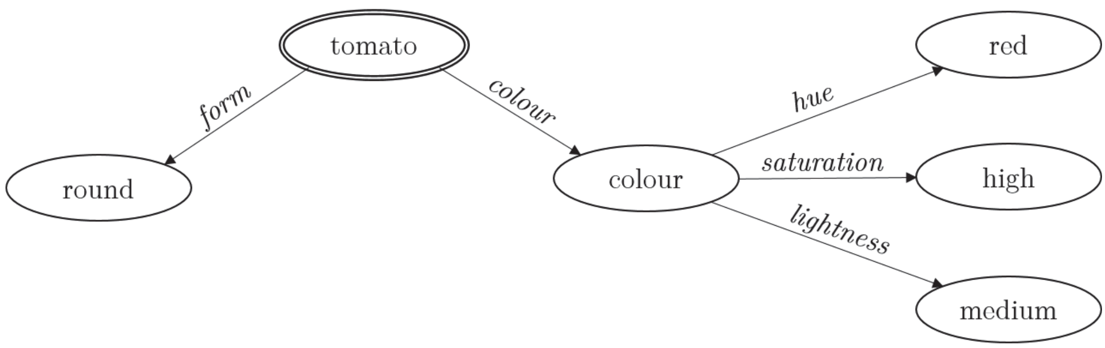

Figure 2-1. Partial, hypothetical frame for the concept “tomato”. The central node is marked by a double circle. Attributes are represented by the labelled arcs; their values are represented by simple circles (see Chapter 2.3.3 for different approaches to further specify the colour attribute).

2.2 A model of language production

Conceptual representations are closely related to the words we use to refer to them (Murphy, 2004). These lexical representations are accessed in language comprehension and production. The present dissertation focuses on the latter, namely, processing of

[2] Other ways to represent frame structures include, for instance, attribute value matrices, as described by Löbner (2015).

spoken words starting with the formulation of an abstract message representing a to-be-conveyed thought, leading to the utterance that can be transmitted to a listener by way of an acoustic signal.[3]

The process of language production comprises multiple encoding stages (e.g., Dell & O'Seaghdha, 1992; Indefrey, 2011; Indefrey & Levelt, 2004; Levelt et al., 1999). Most current models assume at least three encoding stages: semantic encoding, lexical encoding, and articulation. These stages can be distinguished using neuropsychological methods (Indefrey, 2011; Indefrey & Levelt, 2004). Each stage results in an intermediate product, starting with the intention to speak and ultimately forming the articulated word. An additional self-monitoring process detects speech errors during language production. The architecture of these stages and their respective outcomes are outlined in Figure 2-2. Any reference to the stages of language production in the following will be based on WEAVER++, a widely adopted model of speech production, which has also been implemented computationally (Levelt et al., 1999; Roelofs, 1997b), and which assumes a semantic network based on spreading activation between nodes (Dell, 1986). The present dissertation focuses on how concepts are activated as parts of the to-be-conveyed message (conceptual preparation) and how subsequently a lemma gets chosen for word form encoding (lexical selection, Figure 2-2).

[3] The present investigations are limited to spoken language produced by adult, healthy speakers pronouncing words in their native language.

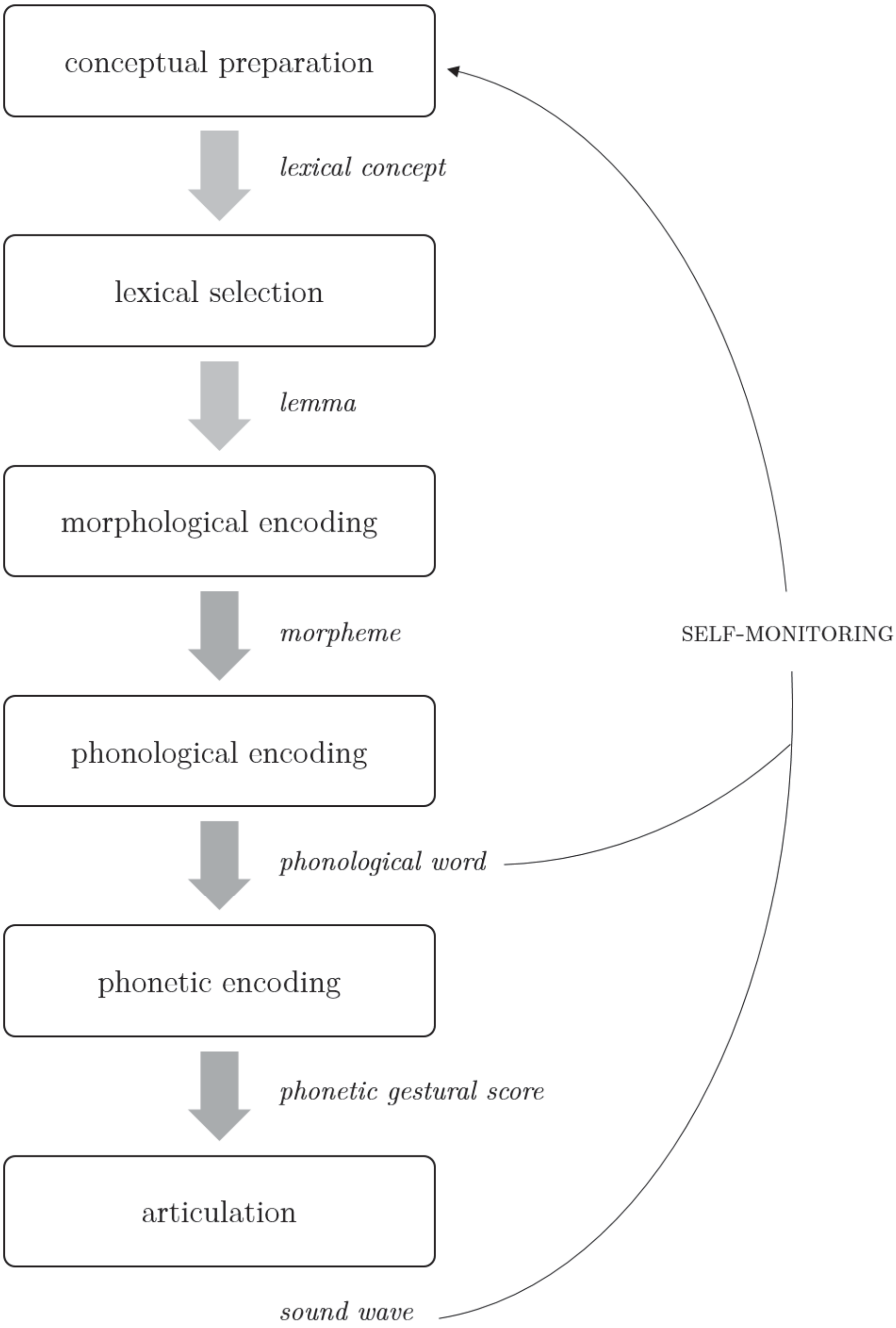

Figure 2-2. Architecture of the language production process (adapted from Levelt, Roelofs, & Meyer, 1999).

2.2.1 A closer look at conceptual preparation and lexical selection

During conceptual preparation, the content of the utterance, that is, some notion of what we would like to express, is determined. This phase consists in the formulation of a preverbal "message", which "represents the features of a to-be-conveyed thought that are necessary for its linguistic encoding" (Ferreira, 2010, p. 834). This message includes knowledge about the content of the utterance itself as well as world knowledge about, for instance, the discourse context or shared knowledge with the interlocutor(s). At the end of this stage, a lexical concept is chosen for further encoding. This lexical concept includes semantic, syntactic, and pragmatic conditions on the usage of the given word (Levelt et al., 1999; Wheeldon & Monsell, 1992). Note that in tasks such as object or picture naming, an additional stage of visual object recognition and matching of the object's form to stored structural representations is a prerequisite to formulating the message (Biederman & Ju, 1988; Humphreys, Riddoch, & Quinlan, 1988).

Once the semantic content of the to-be-uttered word has been determined and a lexical concept has been specified, it is necessary to find the lexical item or "lemma" that best serves to express this concept. The lemma is an abstract representation, including a word's meaning as well as its phonological and morphosyntactic properties. Lemmas are stored in the mental lexicon containing all words that a speaker has in his or her vocabulary.

There is an ongoing discussion about whether lexical selection in language production is a competitive or non-competitive process (for a review, see Spalek, Damian, & Bölte, 2013). Most current accounts assume lexical access to be competitive. According to these views, the speed of selection of the (correct) target word depends on simultaneous co-activation of lexical entries corresponding to related concepts. This co-activation of other lexical candidates slows down selection of the target word, that is, the word that ultimately crosses the activation threshold and is further processed for articulation. This slowing-down can be implemented by lateral inhibition, that is, inhibitory links between lexical candidates (Cutting & Ferreira, 1999), or by spreading activation only (Levelt et al., 1999; Roelofs, 1997b). In the WEAVER++ model, a lemma is selected whenever its activation level exceeds a critical difference to the next-active lexical candidate (following Luce's choice rule, Luce, 2012). Non-competitive accounts, on the other hand, assume that inhibition does not arise at the lexical level, but at a post-lexical processing stage when selecting a response (Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Navarrete, Del Prato, Peressotti, & Mahon, 2014). According to these accounts, lemmas do not compete with each other for lexical selection, but inhibition arises when a possible answer (contained in the set of possible responses) has preferred access to a pre-articulatory output buffer, thereby blocking it and having to be removed before the correct target word can be articulated (Response Exclusion Hypothesis, Mahon et al., 2007).

The present dissertation investigates the mechanisms that determine whether (pre-)activation of a surface attribute has an impact on lexical access. Specifically, it will focus on object colour as an example of a surface feature. The choice of colour as the attribute of interest was based on several considerations: First, there is evidence that surface colour contributes to object recognition and naming. Additionally, when trying to disentangle (pre-)activation of the attribute from processing of the target object's structural properties (Experiments 0, 1 and 2), it seemed reasonable to choose a (perceptual) attribute that is not sufficient for identifying the object (such as shape would be, if not degraded). In the following, I will therefore give a short description of human colour vision (Chapter 2.3.1), previous research on the influence of colour on object recognition and naming (Chapter 2.3.2) as well as the role of colour-diagnosticity (Chapter 2.3.3).

2.3 Colour in object recognition and naming

Being able to see colour is beneficial for humans in a variety of tasks, for instance, when telling apart ripe fruit from a background of green leaves (Osorio & Vorobyev, 2008; Sumner & Mollon, 2000a). In general, colour vision has been shown to help object recognition and visual memory of objects and scenes (for a review and meta-analysis see Bramão, Reis et al., 2011 and Tanaka, Weiskopf, & Williams, 2001). Although it has been a subject of study in many disciplines, an exact definition of what colour constitutes is still under discussion today. Most contemporary approaches describe colour as an interaction between object surface properties (reflectance of light, situational surrounding such as background illumination) and visual perception and processing of colour information in the brain (Schmidt, 1999). In the following, I will highlight several aspects of colour vision and cognitive processing of colour that are helpful for understanding its representation in the human mind and its role as an attribute in frames.

2.3.1 Human colour vision

Colour perception and subsequent processing start in the human eye, from where the signal continues to be transmitted to subcortical and cortical structures (Wolfe et al., 2015). The human eye has several physiological traits that enable colour vision: Besides rod photoreceptors discriminating dark and light, the retina contains three types of cone photoreceptor cells located in the fovea centralis that are specialised to different parts of the electromagnetic spectrum: S-cones (sensitive to short wavelengths of light), M-cones (medium wavelengths) and L-cones (long wavelengths). Humans are thus equipped with trichromatic vision, and can see wavelengths of the electromagnetic spectrum ranging from roughly 400 to 700nm This allows us to discriminate between more than 10 million colours (Wolfe et al., 2015). Different models have been proposed to describe and uniquely identify colours in colour space. One widely adopted model describes colours in terms of hue (chromatic properties), saturation (proportion of hue in light, white light has the least saturation) and brightness (perception of the physical intensity of light, Munsell, 1905; Wolfe et al., 2015). Colour and luminance are further encoded by the retinal ganglion cells and transmitted via the optic nerve to the optic chiasma, and further to colour-sensitive neurons in the thalamus and the lateral geniculate nucleus (LGN). The information is then passed on to the occipital lobe, namely the primary visual cortex (V1), secondary visual cortex (V2), and to V4 and V8 (Bartels & Zeki, 2000; Lueck et al., 1989; Zeki et al., 1991; McKeefry & Zeki, 1997). Whether one or more of these regions can be considered specialised for colour vision is still under debate (Wolfe et al., 2015). In the inferior temporal lobe, colour information is integrated with other information like the shape of the perceived object.

Note that even at this fundamental physiological level, there can be individual differences in colour perception: On the one hand, colour vision can be impaired to different degrees on the subcortical and cortical level (e.g., congenitally, or as a result of a lesion following a stroke, see Schmidt, 1999). Furthermore, encoding of photons at the retinal level can be impaired, such as in cases of colour blindness, were affected patients show an underdevelopment of one of the three cone types, resulting in colour perceptions that differ from those experienced by healthy humans. But also colour vision in healthy humans is inherently ambiguous (Allred, 2012): There is always an interaction between properties of the stimulus (e.g., object material) and properties of the light source, in addition to individual variations in properties and number of photoreceptors as well as an omnipresent photoreceptor noise. Two stimuli that excite the same pattern in the cones can cause a different colour percept depending on the colour that surrounds them, and two stimuli that have different properties can cause the same colour percept

(Gegenfurtner, 2003). Furthermore, an object is perceived to have a constant colour over time even if it is presented under different lighting conditions (colour constancy). Thus, dynamically changed "guessing rules" for the constant colour of an object must be applied depending on the environment (Allred, 2012, p. 214). Hence, even in a normally developed, healthy colour vision system, every instance of perceiving a colour is slightly different. On a cognitive level, colour processing can also be influenced by other, simultaneous processes, as suggested by studies showing that colour memory is error-prone, and tends to be affected by working memory load (Allred & Olkkonen, 2015).

As we have seen so far, there are certainly commonalities in how the healthy human visual system processes colour (subcortically and cortically), but colour perception can also vary on an individual basis. In the following, we will discuss higher-level processing of colour, in particular object categorisation and naming.

2.3.2 Object recognition and naming

Object surface colour has been shown to facilitate low level visual processing of objects and scenes (e.g., Sumner & Mollon, 2000b; Gegenfurtner & Rieger, 2000), as well as later processing stages involved in conceptual and semantic processing (for reviews see Bramão, Reis et al., 2011 and Tanaka et al., 2001). In a review and meta-analysis of 35 experiments, Bramão, Reis et al. (2011) found that particularly in picture naming tasks, object identification benefited from colour information. Therriault et al. (2009), for instance, showed that naming of objects was fastest when they were presented in a correctly coloured version (e.g., a picture of an orange pumpkin), and slowest when they were presented in an incorrectly coloured version (e.g., a blue pumpkin). When pictures were presented in black and white, reaction times were slower than for correctly coloured versions, but faster than for incorrectly coloured versions. The authors attributed these results to a contribution of colour to object recognition alongside object shape, in line with surface-plus-edge based accounts of visual object recognition (Tanaka et al., 2001; but cf. Biederman & Ju, 1988 for edge-based theories). These results were confirmed in multiple studies investigating the influence of object colour on naming (e.g., Davidoff & Ostergaard, 1988; Exp. 2; Ostergaard & Davidoff, 1985; Price & Humphreys, 1989, Wurm et al.,1993, Vernon & Lloyd-Jones, 2003; Rossion & Pourtois, 2004; Schmidt, 1999). Besides naming, colour effects have been reported for memory tasks (Westerbeek, Koolen, & Maes, 2015).

However, other experimental tasks produced less clear-cut results: Whereas effects of object surface colour on picture naming (see Chapter 2.4 for a description of this method) are stable, results were mixed in semantic classification, reading, or object or colour verification tasks. Several studies have failed to find effects of colour in semantic classification tasks. Davidoff and Ostergaard (1988), for example, employed a classification task where participants judged object animacy and size via a vocal response. No significant difference was found between objects presented in colour or in black and white, which the authors interpret as evidence for the fact that colour does not support semantic processing (which is necessary to make categorical judgments about, e.g. animacy).

On the one hand, there is evidence that colour helps object recognition in verification tasks (Gegenfurtner & Rieger, 2000; Therriault et al., 2009). Therriault et al. (2009) showed furthermore that presentation in colour did not only help naming colour-diagnostic objects, but also facilitated verification when participants were presented with an object name followed by a picture of the correctly coloured, incorrectly coloured or achromatic object. On the other hand, some other studies failed to find colour effects in verification tasks (e.g., Biederman & Ju, 1988).

A study by Yee, Ahmed, and Thompson-Schill (2012) on word reading revealed that effects of colour may depend on the experimental context: They observed colour priming in word reading with pairs of typical colours and objects such as *emerald* – *cucumber*, but the effect was only present for participants who had completed a Stroop task prior to the word reading task, thereby focusing attention on the colour attribute. The authors interpret their finding as evidence for a dynamic nature of cognitive representation, since activation of object colour was modulated by task context.

Overall, there is some, but inconclusive evidence about whether surface colour supports object recognition depending on experimental task: Whereas results are robust for naming tasks, there is mixed evidence concerning word reading and object or colour verification, and no colour advantage in semantic classification could be found. This heterogeneity in terms of results has been attributed to different demands on cognitive processes imposed by the different tasks (Bramão, Reis et al., 2011): Whereas colour and object verification tasks do not necessarily involve activation of the object's name, deeper semantic and lexical processing is necessary in picture naming tasks. As Price and Humphreys (1989) argue, colour might be beneficial in tasks such as naming, where processing of the object's semantic features and its name are required, since it helps resolve structural ambiguity between objects (i.e., competition in visual object recognition for objects that have a similar shape). In classification tasks (e.g., when judging whether an object is an animal or not), structural ambiguity might not need to be resolved before responding (as long as the object has the general shape features of an animal, it does not matter which species it belongs to).

2.3.3 Colour-diagnosticity

Another finding in the meta-analysis conducted by Bramão, Reis et al. (2011) was that contributions of object colour to object recognition were largest when the objects used as stimuli were considered high colour-diagnostic (HCD). Colour-diagnosticity refers to the degree to which an object is associated with its typical colour. Bananas, for instance, are closely associated with the colour yellow. Conversely, objects that do not have a typical colour are referred to as low colour-diagnostic (LCD). "Strongly associated" in the case of HCD objects refers to the fact that in association tasks, participants tend to name certain colours as typical of the object (e.g., Rosch & Mervis, 1975), but the studies included in the meta-analysis by Bramão, Reis et al. (2011) differed with respect to how they assessed colour-diagnosticity. Within a frame-theoretical framework, colour-diagnosticity could be described by (under-)specification of the colour attribute: On the one hand, frames for HCD objects such as strawberries contain more or less fixed values for the colour attribute (e.g., [COLOUR: **red**]). On the other hand, the colour attribute is underspecified for LCD objects ([COLOUR: **colour**]). For LCD objects, the underspecification reflects the constraint that any object of the type denoted by the frame (e.g., bikes) must have a colour, but no specific colour is required. It should be noted, however, that also HCD objects tend to have more than exactly one possible colour qualifying an object as an instance of this category. Bananas, for instance, can have different colours ranging from shades of yellow over green and brown. Especially for object categories such as fruit or vegetables, surface colour is highly correlated with other attributes such as ripeness in the case of bananas (this can be modelled within frame theory using constraints in the sense of Barsalou, 1992). It is also possible to model underspeficifation of LCD objects compared to HCD objects at a deeper level of the frame structure, as proposed by Petersen and Werning (2007): They describe a frame for the concept cherry, which contains an attribute-value pair [*colour*: **colour**], whose value is further specified by the attributes [*hue*: **red**] and [*luminance*: **bright**]. It is thus possible that the difference in representation of HCD and LCD objects is situated at the level of the colour attribute, or at the level of its values further specifying the colour (e.g., hue and luminance; Petersen & Werning, 2007). Furthermore, it has been proposed to include occurrence probabilities in frames to model colour typicality (Schurz, 2012). The difference between HCD and LCD objects can thus be described in the degree of specification of the colour attribute (a small set of possible colours vs. many possible colours), and in terms of probabilities.

Some studies have found colour-diagnosticity to be a moderator in how much colour contributes to object recognition (e.g., Naor-Raz, Tarr, & Kersten, 2003; Redmann et al., 2014, 2014; Schmidt, 1999; Tanaka & Presnell, 1999). Tanaka and Presnell (1999), for instance, could show that participants named pictures of HCD objects faster when they were presented in colour than when they were presented in black and white, whereas LCD objects did not benefit from presentation in colour, a result replicated by Redmann et al. (2014). Based on these findings, Tanaka and Presnell (1999) formulated a colour-diagnosticity hypothesis, indicating that colour facilitates object recognition mainly for HCD objects.

The question at which processing stage colour facilitates object recognition and naming has not yet fully been explored (Bramão, Reis et al., 2011). In a task like picture naming, the addition of surface colour could theoretically have a beneficial influence on one or more processing stages, from early visual processing, over mapping of visual information to stored representations, to finding the object’s name. Focusing on early perceptual processing, multiple proposals have been made, often diverging in the question whether colour becomes relevant at the same time as structural properties such as shape and size are computed (Bramão, Reis et al., 2011; Price & Humphreys, 1989), or whether the influence of colour is reserved to later visual processing stages (Davidoff, 1991; Davidoff & Ostergaard, 1988). The assumption that colour helps object recognition already in early visual processing is confirmed by increasing experimental evidence (Cavanagh, 1987; Gegenfurtner & Rieger, 2000; Wurm & Legge, 1993). It is also possible, as suggested by Davidoff (1991) and others, that colour exerts its influence on multiple levels, in early visual processing as well as in later stages, where the visual input can be mapped onto knowledge about typical colours stored in memory.

To explore the processing stages at which colour is relevant for object naming in particular, Bramão et al. (2012) conducted a study using Event-related potentials (ERPs). The ERP technique allows investigating the time course of cognitive processes as a response to a given stimulus (for details on this technique see Chapter 2.5). In their study, they presented pictures of coloured and achromatic HCD and LCD objects. In response, participants named the pictures by typing their name on a keyboard. The authors found evidence for colour benefits in early visual processing for both HCD and LCD objects (P1 and N1 components), which they attribute to a facilitatory effect of colour on image segmentation. They also found an additional, later effect of colour only present for HCD objects (N400), which they attribute to semantic processing (see Lu et al., 2010 for similar findings, albeit in a paradigm that did not involve naming, but detection of stimulus repetition with button-press responses).

In summary, colour has been shown to be a moderator of object recognition and subsequent processing in a variety of tasks, in particular picture naming. Colour effects seem to be particularly strong in the case of HCD objects, which are closely associated with a typical colour. At this point, it is still not entirely clear which levels of perceptual or linguistic processing are affected by colour information. To address this question is one of the aims of the present dissertation. The psycho- and neurolinguistics methods used to explore the activation of the colour attribute in language production will be described in the following.

2.4 Methods in language production research

To gain more insight into the cognitive processes involved in spoken word production, a variety of experimental methods have been used in the past. These methods include behavioural measures such as response error rates, reaction times, and the tracking of eye-movements, as well as, more recently, neuroimaging methods (for a review, see de Groot & Hagoort, 2018). In the following, I will outline the methods employed in the present dissertation and motivate their use.

2.4.1 Picture naming and Picture-Word Interference

Already in the 19th century, experimental psychologists started analysing picture naming latencies to study language production, initially often comparing overt naming latencies to reading latencies (for a comprehensive review on the history of psycholinguistics see Levelt, 2014). In the second half of the 20th century, use of the picture naming paradigm spread and yielded more and more insight into the retrieval of words in naming. In these experiments, properties of the picture or of the object's name were manipulated to study the cognitive processes that underlie naming.

These new insights gained in picture naming studies included, for instance, that high compared to low word frequency of the depicted object's name has a facilitatory effect on reaction times (e.g., Carroll & White, 2018; Jescheniak & Levelt, 1994). These and other findings gave rise to and informed existing models of speech production. Nevertheless, picture naming and the analysis of naming latencies on its own lacked the power to provide insight into the order and timing of processing stages during speech production.

This issue was addressed by introducing an additional stimulus to be presented alongside the to-be-named picture in a so-called picture-word interference paradigm.

In the picture-word interference paradigm (PWI, e.g., Glaser & Glaser, 1989; Schriefers et al., 1990; Lupker, 1979; Roelofs, 1992), participants are instructed to name a picture of an object (the target, henceforth written in small capitals, 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, in the following set in italics, e.g., *horse*). An example of a target picture combined with semantically related and unrelated distractor words is displayed in Figure 2-3. 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, or shortly after the picture. This form of double stimulation is closely related to the Stroop task, where a font colour that is incongruent with the colour word on the screen (e.g., *red* presented in blue) slows down naming of the font colour. Since they are very closely related, the picture-word interference paradigm is often considered a form of Stroop paradigm (MacLeod, 1991; van Maanen, van Rijn, & Borst, 2009; but see Dell'Acqua, Job, Peressotti, & Pascali, 2007). 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.

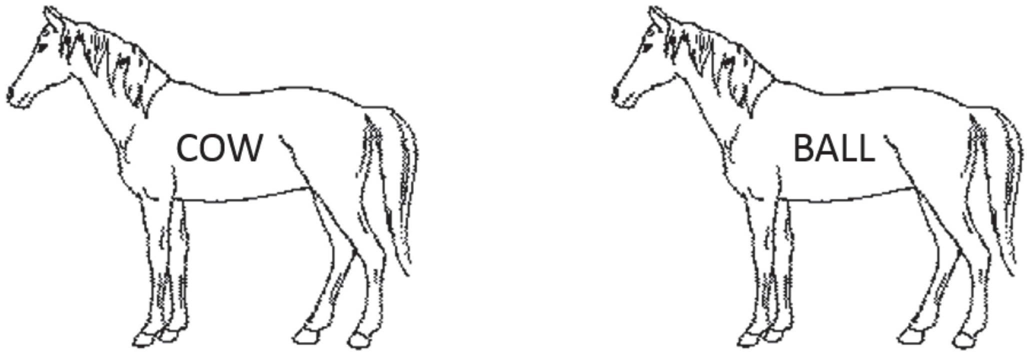

Figure 2-3. Example stimuli in the Picture-Word Interference (PWI) paradigm. Left panel: Semantically related distractor word, right panel: semantically unrelated distractor word (picture taken from the Snodgrass and Vanderwart set, Snodgrass & Vanderwart, 1980).

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 et al., 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 on 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 multiple lexical entries corresponding to the activated concepts. These lexical entries then compete for lexical selection, until the entry that ultimately received 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 stimulus onset asynchronies (SOAs, timing between onset of two experimental stimuli) between -300 and 0ms (Alario, Segui, & Ferrand, 2000; Bölte, Jorschick, & Zwitserlood, 2003; Damian & Spalek, 2014; 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, trend towards interference from associates in Exp. 3) 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, 2009 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 0ms 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, Roemer, 2012). Sailor and Brooks (2014) found that only associatively related distractor-target pairs produced facilitation at SOA -300 and -150ms (but not at SOA 0ms). Conversely, parts that were not associated with the target produced interference at SOA 0ms. Similarly, for distractors denoting a distinctive feature of the target, such as *hump* – CAMEL, Vieth, McMahon, and de Zubicaray, Greig I. (2014) found slower lexical selection at short negative SOAs. In the present dissertation, we focused on activating the value of one particular 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, Hirschfeld et al. (2008; see also Jorschick et al., 2005) showed facilitation at negative SOAs and SOA 0ms.

Apart from manipulating distractor-target relatedness, varying the timing of the distractor stimulus (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.

The present dissertation utilised the picture-word interference paradigm to investigate how activation of the colour attribute affects naming of high and low colour-diagnostic objects (Experiments 1 to 4). To further investigate the processing stage or stages at which colour activation affects naming, SOA was varied such that the distractor was presented before, at the same time, or after the target picture. Although some insight on the time course of these processes can already be gained by means of the PWI paradigm and varying distractor type as well as SOA, neurophysiological methods allow for a more precise investigation of the underlying cognitive processes. Electroencephalography (EEG) in particular enables very precise temporal measurements. Using this technique, the temporal characteristics of language production can be investigated in a much more fine-grained way.

2.5 Electroencephalography and Event-related potentials

Electroencephalography (EEG) is a non-invasive neuroimaging technique widely used in science and for clinical applications (here and the following: Handy, 2005; Jackson & Bolger, 2014; Karnath & Thier, 2006; Luck, 2005). The EEG technique was initially developed by Hans Berger (1929), who conducted several experiments in which he measured voltage changes on the human scalp with the help of electrodes. These voltage changes reflect the sum of excitatory and inhibitory post-synaptic potentials at apical dendrites of pyramidal cells oriented in parallel to each other beneath the electrodes. Amplifying and plotting these voltage changes at each electrode over time yields the electroencephalogram. The EEG signal reflects the difference between voltage at a particular electrode and a reference point. This reference point can be placed at the mastoid or earlobe and re-referenced to the other mastoid or earlobe after data collection, thereby correcting for differences in impedance at the two reference sites. Other methods include referencing over all scalp electrodes.

The raw EEG signal, however, is of limited use when studying cognitive processes, because it represents the combined signal of all brain responses at a given point in time, which may be due to the general mental state of the subject, underlying sensorimotor as well as cognitive processes. A more sophisticated technique to study specific cognitive functions on their own by keeping background noise to a minimum and by disentangling them from other, simultaneous processes consists in analysing event-related potentials (ERPs). ERPs are signal-averaged epochs of EEG signal time-locked to the onset of an event. This event may consist in the immediate reaction to a stimulus, or execution of a motor response. This process results in typical patterns of waveforms, showing transient positive and negative voltage deflections during a specific epoch. These deflections "reflect the sum of several relatively different underlying or latent components" (Handy, 2005, p. 17). To draw conclusions about cognitive processes connected to the given stimulus or motor event, these components can be analysed, for instance, in terms of amplitude, onset, or duration. ERP components have been defined in terms of their polarity (positive or negative), latency, and distribution over the scalp. For instance, the first negative-going deflection with its peak around 100ms after presentation of a visual stimulus is typically referred to as “N1” (for its ordinal position relative to other peaks) or “N100” (for its latency). ERPs have been used in the study of various cognitive processes, including language comprehension and, more recently, production.

2.5.1 Event-related potentials in language production research

Until about a decade ago, ERPs were not often used in the study of overt language production, mainly due to the fact that the articulation of words is linked to complex motor activity that could disturb the recorded signal. Instead, methods like delayed naming or silent (covert) naming were employed (e.g., Schmitt et al., 2001; Schmitt, Rodruigez-Fornelis, Kutas, & Münte, 2001). However, technological advances in the past decade have enabled researchers to avoid these problems, and more and more studies on language production have used EEG since then (e.g., Abdel Rahman & Sommer, 2003; van Turennout, Hagoort, & Brown, 1997; Schmitt, Schiltz, Zaake, Kutas, & Münte, 2001, Laganaro & Perret, 2011; Piai, Roelofs, & van der Meij, 2012; for a review, see Ganushchak, Christoffels, & Schiller, 2011 and Strijkers, Costa, & Thierry, 2012; see Eulitz, Hauk, & Cohen, 2000 for a comparison between overt and covert word production). These studies could show that the interpretation of ERPs up until at least 400ms after stimulus presentation is feasible (Strijkers et al., 2010). In a detailed review of studies on language production using ERPs, Ganushchak, Christoffels, and Schiller (2011) describe several ERP components that have been investigated as to their relation to language processing (e.g., the P2, N300, and N400). In the following, I will give a characterisation of the component of central interest in the present dissertation, the P2 component.

2.5.2 The P2 component

The visual P2 component is the second positive-going component after presentation of a visual stimulus such as a picture, peaking around 150 to 275 ms post stimulus onset at parieto-occipital electrode sites (Dunn, Dunn, Languis, & Andrews, 1998). Previous research has connected the P2 component to a number of underlying cognitive functions such as selective attention (e.g., Hackley, Woldorff, & Hillyard, 1990; Hillyard & Münte, 1984), processing of visual stimulus characteristics such as spatial frequency (Cesarei, Mastria, & Codispoti, 2013; Viggiano & Kutas, 2000) or contrast (Amsel, Urbach, & Kutas, 2014), working memory (Lefebvre et al., 2013), and recall from memory (Dunn et al., 1998). It has also been shown to be sensitive to repetition suppression in priming tasks (Gruber & Müller, 2002).

With respect to language comprehension, the P2 component has been shown to be modulated by semantic discrimination in category verification tasks (Boddy & Weinberg, 1981). Other studies have shown that it is sensitive to the distinction between closed word classes like articles and prepositions, and open word classes such as nouns, verbs and adjectives (e.g., Brown, Hagoort, & Keurs, 1999; Osterhout, Allen, & McLaughlin, 2002). Importantly, it has also been connected to lexical access in language production (Costa et al., 2009; Strijkers et al., 2010; Strijkers, Holcomb, & Costa, 2011). In a picture naming study conducted in Spanish with bilingual speakers of Spanish and Catalan, Strijkers et al. (2010) investigated sensitivity of the P2 component to word frequency and cognate status. They found a more positive-going P2 component for pictures corresponding to low frequency words compared to high frequency words (e.g., ZANAHORIA/'carrot' vs. e.g., ÁRBOL/ 'tree'), and for Spanish-Catalan non-cognates compared to cognates (e.g., span. LIBRO/'book', a cognate to cat. LLIBRE, vs. span. QUESO/'cheese', a non-cognate to cat. FORMATGE). The authors take frequency and cognate status to be connected to lexical access, but acknowledge that this assumption is less confirmed in the case of frequency, which might affect word production at other processing stages. However, given the a priori assumption that ease of lexical access can be manipulated by frequency and cognate status, the authors conclude that the P2 component can be taken to reflect ease of lexical access, with a more pronounced deflection when lexical access is more difficult. Note that Strijkers et al. (2010) stress that the lexical-access-related P2 component has a more posterior scalp distribution than the visual P2 and should thus be differentiated from it.

The present dissertation makes use of these findings to investigate the influence of activation of colour attributes on language production using ERPs (Experiments 1 and 4), thereby focusing on the P2 component to assess whether this potential influence affects the processing stage of lexical access to the target word.

2.6 Objective

The present dissertation focuses on the (pre-)activation of a particular attribute within frames during language production, namely colour. Since colour is a surface feature of physical objects, studies investigating other surface attributes are of particular interest for the present investigations.

Previous research showed facilitation in the picture-word interference paradigm when the surface feature was presented before or at the same time as the target picture. With respect to colour attributes, the literature has provided evidence that colour might play a different role in naming objects that have a typical colour (HCD objects such as bananas) than when naming objects with no typical colour (LCD objects such as bicycles). 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. LCD objects do not seem to benefit from the additional colour information as much as HCD objects. Based on these findings, we conducted a series of studies to investigate potential context effects of an object's typical colour on language production and the time course of such potential effects. The first of these studies will be outlined as Experiment 0 below (Redmann et al., 2014). This study can be considered the starting point for the series of behavioural and electrophysiological experiments at the core of the present dissertation (Experiments 1 to 4).

3 Experiment 0: Previous research

Experiment 0 (as reported in Redmann et al., 2014) consisted of 1) a behavioural experiment (here referred to as Exp. 0a) and 2) an electrophysiological study using ERPs (Exp. 0b).

Experiment 0a was designed to replicate earlier findings indicating that HCD objects presented in colour are named significantly faster than when they are presented in black and white, whereas little to no processing benefit due to addition of surface colour could be found for LCD objects (Bramão, Faísca, Petersson, & Reis, 2010; Rossion & Pourtois, 2004; Tanaka & Presnell, 1999; for a review see Bramão, Inácio, Faísca, Reis, & Petersson, 2011). Thus, in Experiment 0a, we presented coloured and achromatic pictures of HCD and LCD objects in a picture naming paradigm. Our hypothesis was that HCD objects would be named faster in the chromatic condition than in the achromatic condition, and that we would find no such effect for LCD objects. This hypothesis was confirmed by our experimental results, supporting the colour-diagnosticity hypothesis (Tanaka & Presnell, 1999): Coloured HCD objects were named significantly faster than achromatic HCD objects, and no difference was found between coloured and achromatic LCD objects.

In Experiment 0b, we disentangled perception of the object's surface colour from processing of the object's form to be able to find out whether the activation of an attribute such as colour within the object's frame could impact the retrieval of that object's lexical information. Secondly, we wanted to investigate whether this potential effect was modulated by colour-diagnosticity. To this aim, we presented coloured rectangles (and, in a control condition, black and white checkerboard patterns) at 400ms before the to-be-named HCD or LCD target objects in a priming paradigm. We hypothesised that recognition and subsequent naming of HCD objects would benefit from pre-activation of their typical colour, and that HCD objects would be more strongly affected by pre-activation of the colour attribute than LCD objects. To be able to differentiate between effects of pre-activating the colour attribute on different processing stages in the time-course of naming the object, we collected EEG data during overt naming. We focused on the parieto-occipital P2 component, which has been used as an indicator for difficulty of lexical access (Costa et al., 2009; Strijkers et al., 2010). We expected an attenuation of the P2 component for HCD objects presented after their typical colour compared to the achromatic checkerboard pattern condition, and no effect on the P2 for LCD objects.

The results provided no evidence for an effect of pre-activating colour on reaction times compared to the control condition. However, an analysis of the ERP data revealed an increased amplitude of the P2 component in the time window from 180 to 300ms post stimulus onset for HCD objects preceded by their typical colour. This increase was interpreted as reflecting more difficult lexical access to HCD objects when presented with their typical colour. No effect of pre-activation of the colour attribute was found for LCD objects.

In summary, the electrophysiological data from Experiment 0b provided further evidence for the colour diagnosticity hypothesis (Tanaka & Presnell, 1999), showing that processing of HCD objects was affected by pre-activation of the object's typical colour, whereas processing of LCD objects was not influenced by colour priming. However, orthogonally to our initial hypothesis, the electrophysiological results suggested that pre-activation of the colour attribute hindered lexical access to the target word instead of facilitating it. We 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 a TOMATO frame, the value of the colour attribute might be a general shade of red or a particular "tomato-red". Provided the presentation consists of a particular shade of colour, in this case, a tomato-red, it is conceivable that the colour chosen for the colour box in the experiment might not correspond exactly to the shade of colour represented in the target's frame. The specific shade of red chosen to prime TOMATO might, for instance, correspond more closely to the colour represented in the frame for STRAWBERRY. Concepts that receive additional activation at the conceptual level in this way would then act as stronger competitors for selection at the lemma level.

On the other hand, it is possible that the colour box activates a large set of objects that share a typical colour (e.g., a red box might activate the concepts for TOMATO, STRAWBERRY, FIRE TRUCK, etc.), 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 Experiment 0a and b, we were not able to distinguish between these two lines of explanations.

The main goal of Experiment 1 of the present dissertation was to test the first of the two hypotheses: Could inhibitory priming of typical colours in Experiment 0b 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?

4 Experiment 1: Pre-activation of typical colours with colour words

Experiment 1 focused on one of the two previously offered accounts for the lack of a facilitatory semantic priming effect induced by typical colours in Experiment 0b: the possibility that the specific combination of hue, saturation and brightness chosen as a prime to activate the typical colour of a target object did not match the colour specified in the object's frame representation.

4.1 Design and objective

To address this possibility, we conducted a follow up study where we chose a set of colour adjectives as distractors. When presenting a coloured square as distractor in Experiment 0b, it was necessary to choose a single shade of colour for presentation (e.g. a specific shade of red). These colours had been taken from photographs of the object in question and were validated in a pre-study with respect to their appropriateness as a possible colour for this object. Colour representations are also routinely activated by reading colour words, as reported by 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 within language-specific, fuzzy borders, see also Berlin & Kay, 1999; 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 banana frame).[4]

If we indeed presented subtly wrong shades of typical colours in Experiment 0b, resulting in inhibition of lexical access to the target word, we would expect to find facilitation when presenting the distractor as a colour word instead of a box of colour at an SOA of -400ms, corresponding to the SOA used in Experiment 0. Provided colour words activate the same shade of colour that is represented in the concept's frame, we expect facilitated lexical access reflected in faster reaction times and a reduced mean amplitude on the P2 component for HCD objects paired with their typical colour compared to an atypical colour or an unrelated adjective. In accordance with the results found in Experiment 0a and b, 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.

4.2 Methods

4.2.1 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. Six of these participants were recorded as replacements because of recording errors (5 participants), or because the original participant was not a native speakers 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

[4] That is, not taking into account metonymical shifts or metaphorical usage of the target word, such as a person in a banana costume, which could move on his or her own and thus have a *speed* attribute. Since the pictures of the objects did not give any incentive to construct such a context, we would not expect participants to automatically shift, for instance, the concept BANANA to denote a person in a banana costume.

neurophysiological deficits. As a reward for participation, they received study credit or money.

4.2.2 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 and Vanderwart, 1980) and the picture database from the Max Planck Institute for Psycholinguistics in Nijmegen, Netherlands, in the pre-study (see Figure 4-1 for an example of our stimulus materials and trial sequence).[5] Twenty-four native speakers of Dutch, mostly undergraduate students at Radboud University, Nijmegen, took part in the pre-study. On a computer screen, participants were presented with all prospective stimulus pictures. For each picture, they answered the following questions in Dutch (translation as presented to the participants in parentheses):

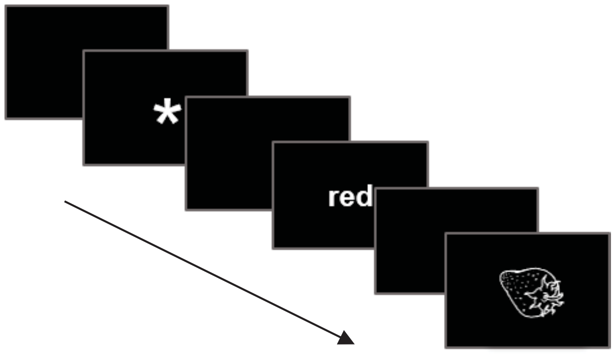

Figure 4-1. Example of a typical trial sequence in Experiment 1 (high colour-diagnostic object with typical colour distractor).

1) "What do you see in this picture" ("Wat zie je in dit plaatje")?

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[5] Line drawings were used instead of photographs as in Experiment 0, 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 Bramão, Reis 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.

2) “Does this object have one (or more) typical colours” (“Heeft dit object één (of meer) typische kleur(en)”?
3) “How often do you encounter this object in your daily life (also in the media or in your thoughts)” (“Hoe vaak kom je het object in het dagelijks leven tegen (ook in de media of in je gedachten)“)?
4) „How easy was it to recognise the picture?“ („Hoe eenvoudig was het om het object te herkennen”)?

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 subjects (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 subjects 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%. 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, R. H., Piepenbrock, R., & van Rijn, H., 1993), object familiarity and difficulty of recognition (Table 4-1). 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, Reis et al., 2011). Since this inherent imbalance could not be resolved, the natural-artificial distinction has to be taken into account when interpreting differences between HCD and LCD stimuli. However, within the HCD and LCD stimulus sets, we made sure to include approximately the same number of natural and artificial objects (cf. Table 4-1). Note that in their meta-analysis on colour-diagnosticity and object recognition, Bramão, Reis 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* – BANAAN; “yellow banana”), since previous research has shown that congruence in terms of grammatical gender can influence language production (for a review, see Schriefers, 1999). Since adjectives are inflected differently when modifying grammatically neutral nouns compared to masculine and feminine nouns in Dutch, we matched the number of grammatically neutral 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 pre-study. Atypical colours were colours that were not named by any subject for a given HCD object in the pre-study. Unrelated adjectives were semantically incongruent as properties of the object and should not 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, H. R., Piepenbrock, R., & van Rijn, H., 1993). For normalisation, we applied log natural transformation ln 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).

Table 4-1. 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 (sum)
HCD	86.6	1.8	2.2	2.8	1.3	47
LCD	13.9	1.8	2.3	3.0	1.2	16

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 subject 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. Blocks were pseudo-randomised using the Shuffle software (Pallier, 2002) (no more than two subsequent trials of the same condition, adjectives and target onset syllables not repeated on subsequent trials) within-block and counterbalanced across participants to avoid carry-over effects.

4.2.3 Procedure

Prior to the experiment, all participants signed 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 60Hz), 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 2000ms, followed by a blank screen (duration between 0 and 200ms). 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 200ms with an interstimulus interval (ISI) of 200ms before presentation of the target picture (resulting in an SOA of 400ms). The target was presented for 2000ms. A blank screen was shown between trials for 3000ms. 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 minutes including eight self-paced breaks.

4.2.4 Analysis of reaction times and accuracy

Naming errors were defined as trials in which subjects 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 balanced set of item names. All such naming errors and naming latencies more than 3 standard deviations (SD) below or above the mean for a particular subject and condition or longer than 2500ms 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). For the analysis of the ERPs, we excluded all trials faster than 600ms to avoid contamination of the EEG signal by speech onset related artefacts (14.3% of all trials). In order to be able to directly compare results between the ERP and reaction time analyses, we also excluded these fast trials from further reaction time analyses. We did, however, include these trials in the analysis of speech errors, since they were considered valid responses as defined by the above-named criteria.

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). As Baayen, Davidson, and Bates (2008) could show, linear mixed models can be considered an effective method for analysing data in designs commonly found in psycholinguistics, including repeated-measures design such as the designs in Experiments 1 to 4 of the present thesis. 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). However, as Barr et al.

(2013, p. 276) point out, “it is altogether possible and unfortunately common that the estimation procedure for LMEMs [linear mixed effects models, AR] will not converge with the full random-effects specification” (non-convergence). In these cases, which are specifically prone to occur with multifactorial designs with relatively few observations, the degrees of freedom can be insufficient for random effects estimation, causing a failure to converge when running the model in R. According to Barr et al. (2013), this is especially problematic for categorical as opposed to continuous data. When faced with non-convergence, Barr et al. (2013) propose the following considerations:

First, it is important to rule out problems with the input data or the model estimation procedure itself, such as misspecifications of predictors or outliers that could be eliminated by standard outlier correction procedures. Centering the predictors or increasing the number of iterations in the estimation procedure can also be beneficial. If it is indeed necessary to cut down on the random effects structure, Barr et al. (2013, p. 276) propose the following “rule of thumb”:

> “[*F*]or whatever fixed effects are of critical interest, the corresponding random effects should be present in that analysis. For a study with multiple fixed effects of theoretical interest, and for which a model including random effects for all these key effects does not converge, separate analyses can be pursued.”

Thus, in cases of non-convergence, we conducted 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 consider 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 to be shorter compared to the atypical colour and unrelated adjective distractors, all p values reported are one-sided. 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) in Experiments 1 to 4, since the raw reaction times exhibited a positive skew, and plots of the model residuals suggested skew and heteroscedasticity (see Appendix for an example of plotting the residuals and fitted values as well as quantile-quantile plots of the standardized residuals in the untransformed and transformed data).

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. Pairwise comparisons were conducted using the function glh*t()* (package "multcomp", Hothorn, Bretz, & Westfall, 2008), using the Bonferroni-correction for multiple comparisons.

4.2.5 EEG recording and analysis

The EEG signal was recorded continuously from 32 tin electrodes. We used an active electrode cap (ActiCap) and recorded from 27 scalp electrodes embedded in the cap at the following sites: Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, O2. We registered vertical and horizontal eye movements with three additional facial electrodes placed next to the left and right eye, and below the left eye. Scalp electrodes were referenced on-line to the left mastoid and re-referenced offline to linked mastoids. Impedances were reduced to 15 kΩ or less during electrode application, with the amplifier impedance set to 10 MΩ (cf. Ferree et al., 2001). EEG and EOG signals were amplified using a BrainAmp DC amplifier (Brain Products, München, Germany), and sampled at 500 Hz with a high cut-off filter at 125 Hz and a low cut-off filter with a time constant of 10s. A bandpass filter of 0.3 to 20Hz was applied to the EEG data before segmentation. The continuous EEG was split up into epochs from 200ms before target picture onset until 500ms post target picture onset to avoid contamination from speech onset. Trials with deflections exceeding 100 µV or visible muscle or eye-blink artefacts were excluded from analysis (10% of all correct responses, range = 1-32% of correct responses per participant). Before further analysis, we applied a baseline correction (-200 to 0ms before onset of the target picture) and calculated averages per subject, electrode site and experimental condition.

To explore interactions of colour diagnosticity and distractor type in the EEG, we conducted time window analyses with the following time windows: 1) 80-120ms, 2) 120-180ms, 3) 200-250ms, 4) 250-320ms, 5) 320-400ms. Time windows were based on previous literature (Strijkers et al., 2010, Redmann et al., 2014) and visual inspection of the grand-averaged data. For each of these time windows, we carried out repeated-measures ANOVAs over the mean amplitudes from the grand average. We included Colour-Diagnosticity (HCD, LCD), Distractor Type (typical colour [TC], atypical colour [TC], unrelated adjective [UA]), Anteriority (midline, frontal and posterior) and Laterality (central, left and right) as factors in the ANOVAs (see Figure 4-2 for electrode positions). Electrode locations were clustered according to the two factors Anteriority and

Laterality. For Anteriority, the coding was the following: frontal (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6), midline (T7, C3, Cz, C4, T8), posterior (CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, O2). Electrode Laterality was coded as follows: left (Fp1, F7, F3, FC5, FC1, T7, C3, CP5, CP1, P7, P3, O1), central (Fz, FCz, Cz, Pz), right (Fp2, F4, F8, FC2, FC6, C4, T8, CP2, CP6, P4, P8, O2). As in the reaction time analysis, we used a significance criterion of $p < 0.05$. Where appropriate, significance levels are reported after Greenhouse-Geisser correction.

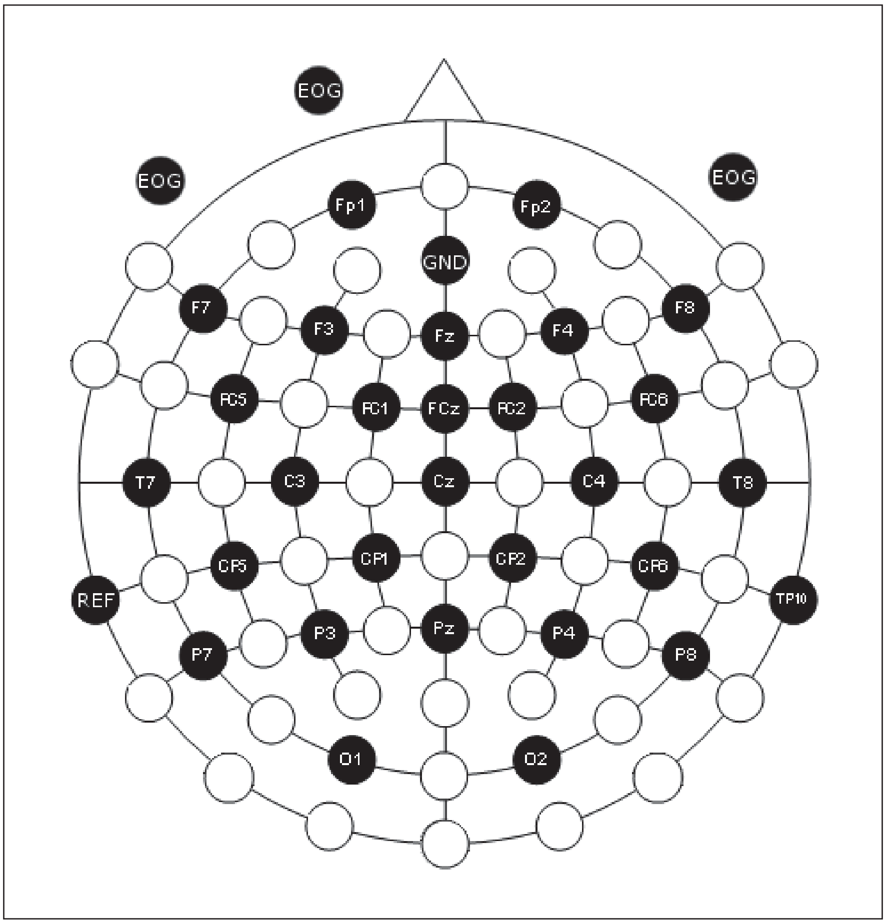

Figure 4-2. Electrode positions in Experiment 2 relative to the 10-20 system. Adapted from http://www.easycap.de.

4.3 Results

4.3.1 Behavioural results

4.3.1.1 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. Unless otherwise noted, significant main effects, interactions, contrasts or post-hoc comparisons remained significant at $p < 0.05$ using all other theoretically justified random effects structures that did not result in non-convergence of the model estimation procedure.[6] Mean reaction times are displayed in Figure 4-3.

Colour-Diagnosticity affected reaction times ($\chi2(1) = 10.134$, $p = 0.001$: HCD objects were named more slowly than LCD objects by on average 42ms. There was no main effect of Distractor Type ($\chi2(2) = 0.194$, $p = 0.908$), but a main effect of Block ($\chi2(2) = 681.42$, $p < 0.001$). Naming responses were 65ms faster on the second block compared to the first block ($t(9394.04) = 18.848$, $p < 0.001$), and 22ms faster on the third block compared to the second block ($t(9421.70) = 7.129$, $p < 0.001$). There was no significant interaction between Colour-Diagnosticity and Distractor Type ($\chi2(2) = 0.6554$, $p = 0.721$), and no three-way interaction between Colour-Diagnosticity, Distractor Type and Repetition ($\chi2(12) = 11.527$, $p = 0.484$).

To be able to better compare the present results with the results obtained in Experiment 0b, which features 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 conducted sub-analyses for the three blocks. Furthermore, as suggested by Piai et al. (2012), it is appropriate to analyse reaction times separately for different levels of a

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[6] We chose this random effects structure, because it was the maximally possible one that could be used for all models within this experiment.

factor if they are expected to differ more than between the levels of other factors of interest, so that collapsing over conditions (in this case, levels of the factor Block) could wash out potential effects of interest.

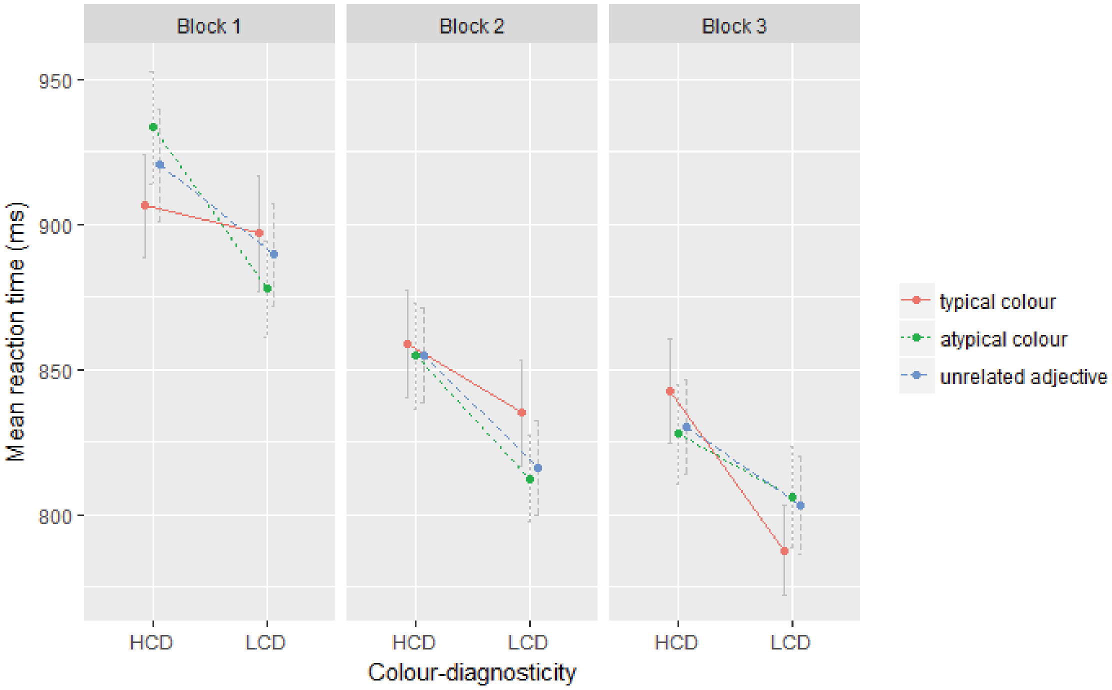

Figure 4-3. Mean reaction times in ms for high and low colour-diagnostic objects (HCD, LCD) paired with typical colour (TC), atypical colour (AC) or unrelated adjective distractor (UA) for the three blocks (1,2,3) in Experiment 1. Error bars indicate 95% confidence intervals around the mean calculated using participants as id variable.

As suggested by the overall analysis, there was a main effect of Colour-Diagnosticity present in all three blocks (all $p < 0.05$)[7], and no main effect of Distractor Type in any of them (all $p > 0.05$). Colour-Diagnosticity and Distractor Type interacted in the first block ($\chi2(2) = 6.921$, $p = 0.031$). Planned contrasts aimed at exploring the congruency effect (comparing HCD objects with their typical colour as distractor to an atypical colour and the neutral condition, an unrelated adjective) revealed that on the first block, HCD objects

[7] For the analysis of the third block, the random effects structure had to be further simplified (omitting the by-item slope for Distractor Type) to achieve convergence of the model.

preceded by their typical colour were named on average 26ms faster than when preceded by an atypical colour ($t(170.61) = -2.009$, $p = 0.023$). There were no interactions in the second or third block.

4.3.1.2 Error rates

There was no significant main effect of Colour-Diagnosticity ($\chi 2(1) = 0.126$, $p = 0.712$) or Distractor Type ($\chi 2(2) = 1.120$, $p = 0.549$). There was, however, a highly significant main effect of Block ($\chi 2(2) = 52.361$, $p < 0.001$): On the second block, fewer naming errors were made compared to the previous one (z = -7.440, $p < 0.001$), 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 by-block analysis revealed no significant main effects or interactions in any of the three blocks (all $p > 0.05$).

Table 4-2. 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

4.3.2 Electrophysiological results

Visual inspection of the grand-average waveforms suggested different peaks at posterior sites compared to frontal and central sites (see Figure 4.4 for grand-averaged mean amplitudes at representative electrodes). At posterior sites, there were peaks between 80 and 120ms (P1), 120 and 180ms (N1), 200 and 250ms (P2), 250 and 320ms (N300), as well as 320 and 400ms (P3) post target picture onset. This sequence observed at posterior electrodes corresponds to the typical pattern in response to visual stimuli (Wixted & Wagenmakers, 2018). At frontal and central electrodes, there were fewer visible peaks, at 80 to 160ms, 160 to 240ms, 240 to 340ms, and one from 340 to 400ms. We chose the time windows fit to the waveforms morphology at posterior sites for the omnibus analysis, since our primary component of interest was the posterior P2 component. However, we conducted additional analyses at frontal and central electrode sites for those time windows that fit waveform morphology at these sites, but were not already present in the omnibus analysis. For the sake of brevity, these analyses are included in the appendix, since the posterior areas were of main interest for our research questions. We used repeated-measures ANOVA and post-hoc comparisons with Bonferroni-correction to explore main effects and interactions. Main effects or interactions involving exclusively the factors Anteriority and Laterality will not be reported.

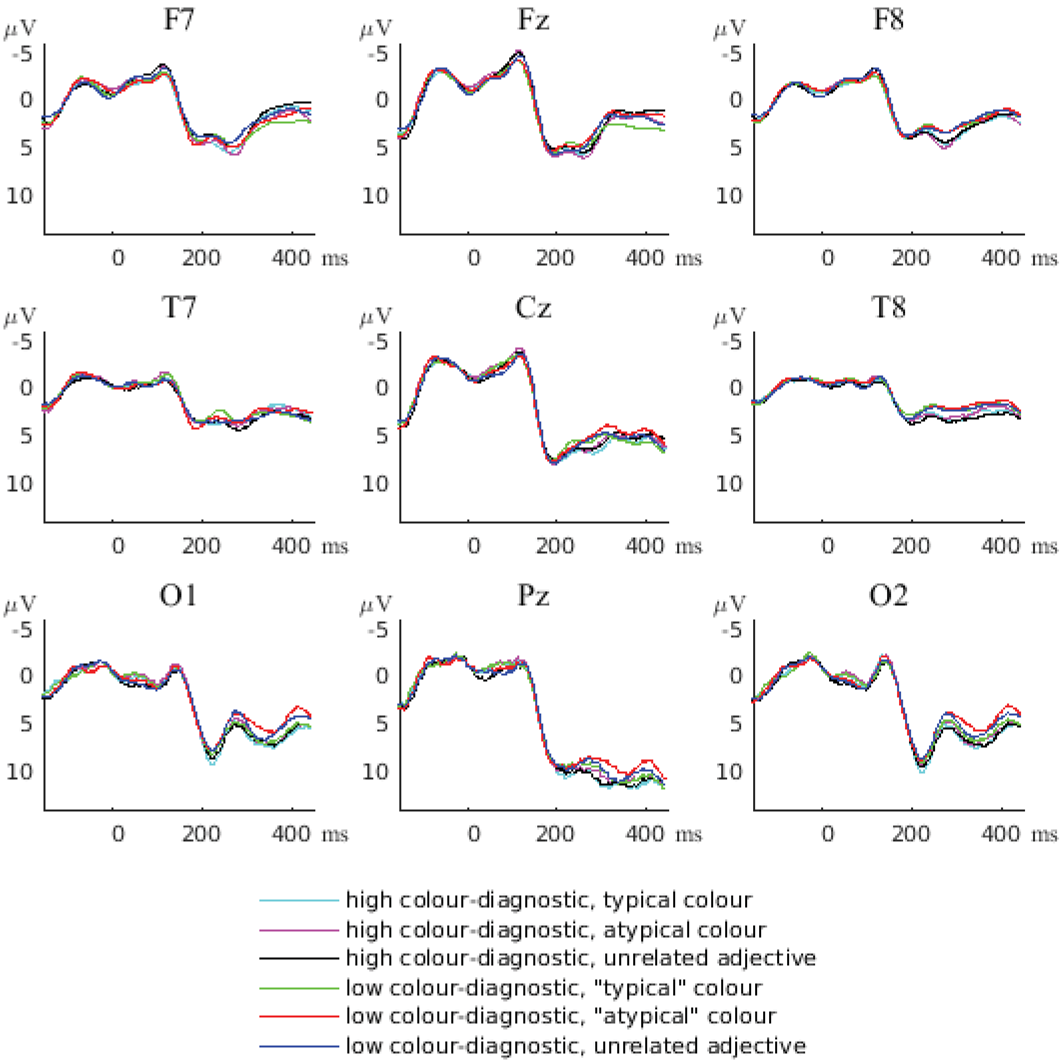

Figure 4-4. Grand-averaged amplitudes for high and low colour-diagnostic objects paired with typical colour distractors, atypical colour distractors, and unrelated adjectives at example electrodes in Experiment 1.

4.3.2.1 Omnibus analysis

80-120ms (P1)

In this time window, the repeated-measures ANVOA yielded no significant main effects. There was an interaction of Block and Laterality ($F(4,116) = 3.812$, $p = 0.006$, es= 0.116), as well as a three-way interaction between Block, Anteriority and Laterality ($F(5.062, 148.792) = 2.429$, $p = 0.037$, *pes* = 0.077). Separate ANOVAs at all levels of Laterality showed that even though there was a main effect of Block at central electrode sites

($F(1.637, 47.462) = 3.614$, $p = 0.043$, *pes* = 0.111), post-hoc tests showed no significant differences between blocks (all $p > 0.1$, see Table 4-3).

At left ($F(1.647, 47.751) = 1.892$, $p = 0.160$, *pes* = 0.061) and right ($F(1.501, 43.515) = 1.377$, $p = 0.260$, *pes* = 0.045) electrode sites, there was no significant effect of Block. We found no further interactions between Block and Anteriority at any level of Laterality (all $p > 0.05$).

Furthermore, there was a significant interaction between Distractor Type and Anteriority ($F(2.208, 64.021) = 6.051$, $p = 0.003$, *pes* = 0.173). Follow up analyses in the form of independent ANOVAs at the different levels of Anteriority did not reveal significant effects of Distractor Type (all $p > 0.05$). At posterior electrode sites, the effect of Distractor Type was marginally significant ($F(2,58) = 3.128$, $p = 0.051$, *pes* = 0.097), however, none of the pairwise post-hoc comparisons were significant (all $p > 0.1$).

120-180ms (N1)

In this time window, we found a significant effect of Block ($F(1.646, 47.723) = 3.933$, $p = 0.034$, *pes* = 0.119), however, post-hoc comparisons did not show significant differences between blocks (all $p > 0.05$, see Table 4-3).

Again, there was a significant interaction of Distractor Type and Anteriority ($F(2.316, 67.158) = 4.639$, $p = 0.010$, *pes* = -0.138). Follow up analyses showed that there was no effect of Distractor Type at midline ($F(1.762, 51.094) = 1.063$, $p = 0.352$, *pes* = 0.035) and posterior electrode sites ($F(2, 58) = 0.252$, $p = 0.778$, *pes* = 0.009). At frontal electrode sites, the effect reached significance ($F(1.859, 53.897) = 4.073$, $p = 0.022$, *pes* = 0.025), but post-hoc comparisons between distractor types were all non-significant (all $p > 0.05$). There were no other significant main effects or interactions in this time window.

200-250ms (P2)

There was a marginally significant trend for a main effect of Colour-Diagnosticity in the P2 time window ($F(1,29) = 3.694$, $p = 0.064$, *pes* = 0.113, Figure 4-5). Amplitudes for HCD objects (mean amplitude = 6.461, standard error = 0.534) were more positive than for LCD objects (*M* = 6.035, *SE* = 0.583).

Furthermore, there was a main effect of Block ($F(2,38) = 25.654$, $p < 0.001$, *pes* = 0.469, Figure 4-6) as well as an interaction between Block and Laterality ($F(4,116) = 10.420$, $p < 0.001$, *pes* = 0.264). Independent ANOVAs at all levels of Laterality yielded a highly significant effect of Block at central ($F(2,58) = 27.401$, $p < 0.001$, *pes* = 0.486), left ($F(2,58) = 20.983$, $p < 0.001$, *pes* = 0.420), and right electrode sites ($F(1.666, 48.304) = 17.382$, $p < 0.001$, *pes* = 0.375). Post-hoc comparisons showed that at all levels of Laterality, the second block was more positive than the first block, whereas the third block did not differ significantly from the second block (see Table 4-3 for mean values and post-hoc comparisons).

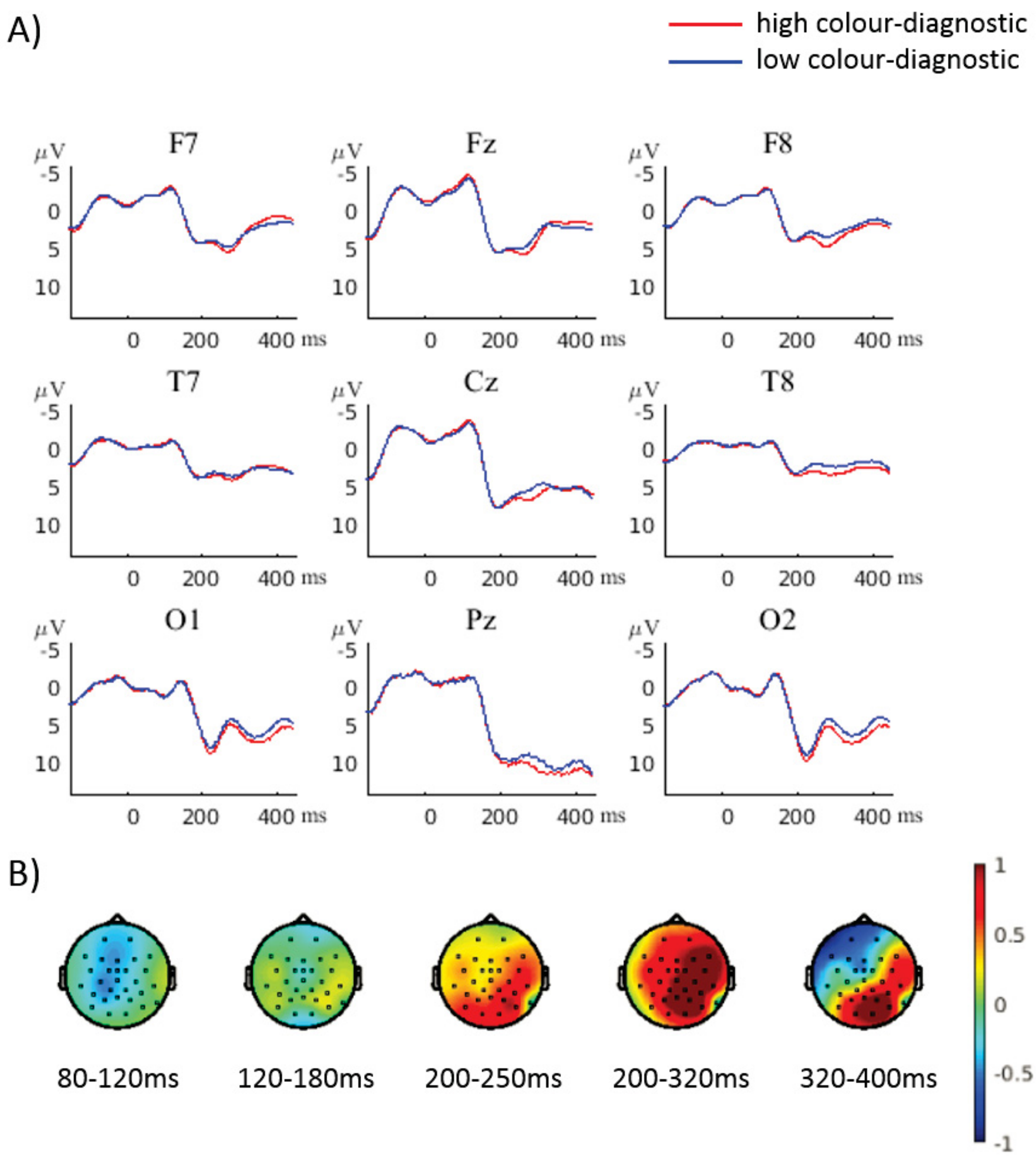

Figure 4-5. A) Grand-averaged amplitudes for high and low colour-diagnostic objects (HCD, LCD) at example electrodes in Experiment 1. B) Scalp topographies of difference between high and low colour-diagnostic objects across time windows.

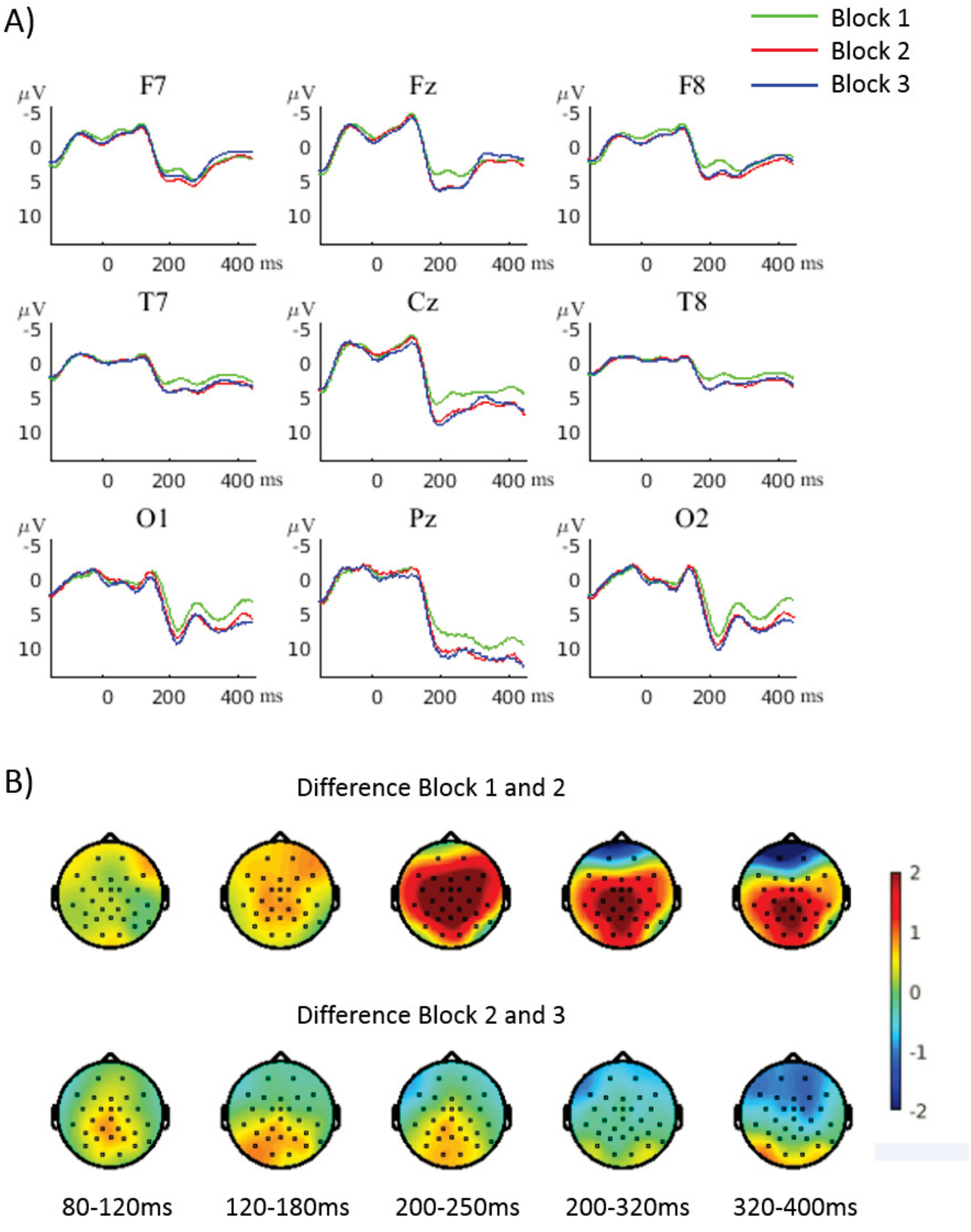

Figure 4-6. A) Grand-averaged amplitudes for Blocks 1, 2 and 3 at example electrodes in Experiment 1. B) Scalp topographies of difference between Block 1 and 2 and between Block 2 and 3 across time windows.

250-320ms (N300)

The repeated-measures ANOVA yielded a highly significant main effect of Colour-Diagnosticity in this time window ($F(1,29) = 28.606$), $p < 0.001$, *pes* = 0.497). In addition to the main effect, Colour-Diagnosticity interacted with Laterality ($F(2,58) = 6.832$, $p = 0.002$, *pes* = 0.190). Separate ANOVAs for all levels of Laterality revealed a significant effect of Colour-Diagnosticity at central electrode sites ($F(1,29) = 25.821$, $p < 0.001$, *pes* = 0.471). HCD objects (*M* = 7.080, *SE* = 0.889) elicited more positive deflections than LCD objects (*M* = 6.026, *SE* = 0.945), that is, the N3 was less pronounced for HCD objects. The effect of Colour-Diagnosticity was also significant at left electrode sites ($F(1,29) = 10.883$, $p = 0.003$, *pes* = 0.273). As on central electrodes, HCD objects (*M* = 5.713, *SE* = 0.639) showed a more positive waveform than LCD objects (*M* = 5.073, *SE* = 0.663). The same pattern was present at right electrodes, where there was an even larger main effect of Colour-Diagnosticity ($F(1,29) = 41.675$, $p < 0.001$, *pes* = 0.590). Again, HCD objects (*M* = 5.747, *SE* = 0.694) showed more positive waveforms than LCD objects (*M* = 4.650, *SE* = 0.705).

We also found a main effect of Block ($F(1.517, 43.984) = 8.973$, $p < 0.001$, *pes* = 0.236). Post-hoc tests revealed that the second block elicited more positive waveforms than the first, whereas there was no significant difference between the third and second block.

A three-way interaction between Distractor Type, Block and Laterality became significant ($F(8,232) = 1.994$, $p = 0.048$, *pes* = 0.064), but did not reach significance in further independent ANOVAs at all levels of Laterality (all $p > 0.1$). No other significant main effects of interactions were present in this time window.

320-400ms (P3)

The repeated-measures ANOVA did not yield a main effect of Colour-Diagnosticity in this time window, but Colour-Diagnosticity interacted with Anteriority ($F(1.440, 41.754) =$

20.649, $p < 0.001$, *pes* = 0.416) and Laterality ($F(2,58) = 9.045$, $p < 0.001$, *pes* = 0.238). There was a trend towards a three-way interaction between Colour-Diagnosticity, Anteriority and Laterality ($F(2.900, 84.106) = 2.445$, $p = 0.072$, *pes* = 0.078). To explore the interaction with Anteriority, we conducted independent ANOVAs at all levels of Anteriority. The effect of Colour-Diagnosticity was highly significant over posterior electrodes ($F(1,29) = 22.406$, $p < 0.001$, *pes* = 0.436), where HCD objects (*M* = 8.611, *SE* = 0.855) elicited more positive waveforms than LCD objects (*M* = 7.814, *SE* = 0.852). On frontal ($F(1,29) = 1.026$, $p = 0.365$, *pes* = 0.034) and midline electrodes ($F(1,29) = 1.431$, $p = 0.241$, *pes* = 0.047), the effect was nonsignificant. To further investigate the interaction with Laterality, additional separate ANOVAs were conducted to all levels of Laterality. The effect of Colour-Diagnosticity was only significant over right electrodes ($F(1,29) = 13.305$, $p = 0.001$, *pes* = 0.315), where waveforms for high colour-diagnostic objects (*M* = 4.825, *SE* = 0.811) were again more positive than those for LCD objects (*M* = 4.224, *SE* = 0.813). In summary, the analysis showed that the effect of Colour-Diagnosticity was limited to right posterior electrodes.

The analysis also yielded a main effect of Block ($F(2,58) = 4.015$, $p = 0.023$, $p = 0.122$), and an interaction between Block and Anteriority ($F(2.033, 58.955) = 11.013$, $p < 0.001$, *pes* = 0.275). Independent ANOVAs at all levels of Anteriority revealed significant main effects of Block at midline ($F(2,58) = 6.490$, $p = 0.003$, *pes* = 0.183) and posterior electrode sites ($F(2,58) = 45.924$, $p < 0.001$, *pes* = 0.613), but not at frontal electrodes ($F(2,58) = 1.217$, $p = 0.303$, *pes* = 0.040). At midline and posterior electrode sites, the first block elicited more positive waveforms than the second block as revealed in Bonferroni-corrected post-hoc comparisons (midline: $p = 0.004$, *SE* = 0.138; posterior: $p = 0.001$, *SE* = 0.430). There was no significant difference between the second and third block ($p = 1.000$, *SE* = 0.412).

There was a significant interaction between Distractor Type and Anteriority ($F(2.259, 65.513) = 3.419$, $p = 0.033$, *pes* = 0.105), however, separate ANOVAs at all levels of Anteriority did not reveal any significant main effects of Distractor Type (all $p > 0.05$). Similarly, a four-way interaction between Colour-Diagnosticity, Distractor Type, Presentation and Laterality was significant in the omnibus analysis ($F(8,232) = 2.350$, $p = 0.019$, *pes* = 0.75), but was nonsignificant throughout all follow up analyses at the different levels of Laterality (all $p > 0.1$).

Table 4-3. Mean amplitudes in *mV* (standard error) for block 1, 2 and 3 over left, central and right electrodes and p-values for Bonferroni-corrected pairwise comparisons between the 1st and 2nd, and between the 2nd and 3rd block in the omnibus analysis.

		Block 1	Block 2	Block 3	1 vs. 2	2 vs. 3
80-120ms	Central	-2.972 (0.664)	-2.766 (0.644)	-2.063 (0.554)	p = 1.000	p = 0.205
	Left	-1.788 (0.544)	-1.542 (0.527)	-1.212 (0.412)	p = 0.877	p = 0.831
	Right	-1.462 (0.467)	-1.326 (0.433)	-1.027 (0.399)	p = 1.000	p = 0.796
120-180ms	Central	-0.721 (0.884)	-0.278 (0.806)	-0.258 (0.701)	p = 0.609	p = 0.582
	Left	-0.565 (0.681)	-0.104 (0.632)	0.290 (0.525)	p = 0.364	p = 0.135
	Right	-0.690 (0.615)	-0.302 (0.567)	-0.079 (0.504)	p = 0.212	p = 0.363
200-250ms	Central	5.414 (0.671)	8.000 (0.784)	8.568 (0.693)	***p* < 0.001***	p = 0.337
	Left	4.379 (0.544)	6.217 (0.610)	6.458 (0.552)	***p* < 0.001***	p = 1.000
	Right	4.430 (0.509)	6.301 (0.577)	6.466 (0.545)	***p* < 0.001***	p = 1.000
250-320ms	Central	5.291 (0.980)	7.267 (1.011)	7.101 (0.866)	***p* = 0.001****	p = 1.000
	Left	4.529 (0.699)	5.945 (0.704)	5.704 (0.636)	***p* = 0.003****	p = 1.000
	Right	4.389 (0.737)	5.716 (0.777)	5.490 (0.664)	***p* = 0.003****	p = 1.000
320-400ms	Central	5.164 (1.089)	6.730 (1.236)	6.197 (1.082)	***p* = 0.022***	p = 0.644
	Left	3.875 (0.762)	4.977 (0.871)	4.611 (0.791)	***p* = 0.042***	p = 1.000
	Right	4.001 (0.809)	5.041 (0.916)	4.532 (0.802)	***p* = 0.059.**	p = 0.481

. p < 0.1; * p < 0.05; ** p < 0.01; *** p < 0.001

4.3.2.2 Summary of electrophysiological results

The time window analysis of the electrophysiological data showed that throughout the whole scalp, neither Colour-Diagnosticity, Distractor Type, nor Block had an impact on ERPs in the earliest two time windows (N1/P1). In the P2 time window, there was a trend for HCD objects to elicit a larger positivity than LCD objects. Presenting the items in three blocks allowed us to also observe potential repetition effects on the waveforms. Throughout all scalp regions, waveforms for the second block were more positive than those for the first block, whereas there were no significant differences between the second and third block. Both the effect of Colour-Diagnosticity and the effect of Block lasted throughout the following time windows (labelled N300 and P3) at all scalp sites.

4.4 Discussion

Experiment 1 investigated whether pre-activation of an object's typical colour in a PWI paradigm facilitates naming of the target picture, and whether this potential facilitation is modulated by colour-diagnosticity of the target object. Furthermore, we collected ERP data to get insight into whether and how this potential facilitation has repercussions for different stages of the naming process.

4.4.1 Behavioural effects

4.4.1.1 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 our results from Experiment 0a and b and other studies in the literature (e.g., Bramão et al., 2010; 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; Redmann et al., 2014; 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).

4.4.1.2 Congruency effect

Crucially, reaction times in Experiment 1 also revealed a congruency effect: 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 0ms (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). The congruency effect found in Experiment 1 contrasts with our results from Experiment 0b, 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 Experiment 1 is consistent with the hypothesis that in Experiment 0b, 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. This mechanism has been described by, among others, Abdel Rahman and Melinger (2009), and is compatible with both competitive and non-competitive accounts of lexical access (cf. Geng, Kirchgessner, & Schnur, 2013; Mädebach, Kieseler, & Jescheniak, 2017). Note that the behavioural congruency effect was only found in the first block, whereas it was absent in blocks two and three. Although most studies investigating semantic facilitation in picture naming did not analyse how item repetition affects the influence of distractor words, Aristei et al. (2011) found that semantic facilitation effects can be short-lived and may diminish with multiple presentations of the item, which is in line with the present findings.[8]

4.4.1.3 Repetition priming

In Experiment 1, repeated naming of the same picture resulted in shorter reaction times. Repeated picture naming has been shown previously to facilitate naming on subsequent trials (La Heij, Puerta-Melguizo, van Oostrum, & Starreveld, 1999; Mitchell & Brown, 1988). One or more processing levels could be involved in these repetition priming effects in picture naming (additively or interactively), including visual perception of the object, conceptual processing, lexical access or post-lexical processing of its corresponding word form (Francis, 2014).

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[8] Aristei et al. (2011) take "first presentation" to refer to the first presentation of an item in a given condition, whereas in our case, each picture was presented only once with each distractor, so that we consider "first presentation" to mean the first presentation of the item irrespective of the distractor word it appears with.

Concerning the role of early visual perception, a review by Francis (2014) found that it is not likely to influence repetition priming, as suggested by studies manipulating visual object properties of repeated items such as spatial frequency, colour and size. These findings have also been confirmed by neurophysiological studies showing that repeated presentation of pictures or repeated semantic classification (e.g., of *cat* and *lion* as *feline*) does not reduce neuronal activation in V1 and V2 (e.g., van Turennout, 2003).

Changes of viewpoint or exemplar, on the other hand, preserved repetition priming, but reduced the effect in comparison to repeated presentation of an identical picture (Bar & Biederman, 1998; Bartram, 1974; Warren & Morton, 1982). According to Francis (2014), this finding suggests that even though early visual processing is not involved in repetition priming effects, later, higher-level visual processing of the object might have an influence, and that exemplar-general priming may reflect "matching a visual object category to a conceptual representation" (Francis, 2014, p. 1304).

There is evidence that repetition priming is influenced by later, lexical or post-lexical processing of the picture's name, or both. It remains unclear, however, how much of this effect can be attributed to speeded lexical access, or speeded access to the phonological form (Francis, 2014). For instance, repetition priming effects are influenced by word frequency: High frequency words tend to show a reduced repetition priming effect (Forster & Davis, 1984; Scarborough, Cortese, & Scarborough, 1977). This finding could be interpreted in favour of a lexical locus of the repetition priming effect. However, this interaction between frequency and repetition priming was not replicated when controlling for age of acquisition in a study by Barry, Hirsh, Johnston, and Williams (2001), who concluded that the locus of repetition priming is likely at the level of retrieving the phonological word form (see also Jescheniak & Levelt, 1994, who found a robust frequency effect over three repetitions).

Taken together, previous research suggests that repetition priming is effective both during lexical selection and phonological encoding: Barry et al. (2001), for instance, argue that since form-only repetition priming effects tend to be more short-lived than repetition priming of words, a solely post-lexical locus of repetition priming is unlikely. This claim was supported by Wheeldon and Monsell (1992), who presented homophones as primes before the target picture (*hair* – HARE), and did not observe repetition priming when eliminating priming of the word forms' visual code in this way.[9]

Finally, it is conceivable that repeated articulation is the driving factor behind repetition priming. However, experimental evidence speaks against this possibility (Francis, 2014). Wheeldon and Monsell (1992), for instance, found that picture naming was also facilitated after reading a definition of the target concept, without having encountered the target word given as a response on the subsequent naming trial (see also Lee & Williams, 2001). According to the authors, this excludes the possibility that having uttered the word on a previous trial drives the repetition effect, however, explicit naming of the object upon reading its definition cannot be excluded.[10]

To recapitulate, previous research suggests that repetition priming observed in the present study could have been effective on multiple levels of processing the target, including higher-level visual processing of the objects, access to the lemma and to the phonological word form. A very early visual or an articulatory locus seem unlikely (Francis, 2014; Stark & McClelland, 2000; Wheeldon & Monsell, 1992). It has also been suggested that repetition priming after the first presentation of a picture reflects perceptual stages of processing, whereas further repetitions might be facilitated by

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[9] But see Stark and McClelland (2000), who found that also nonwords formed by random letter strings could be identified more quickly when they had been previously presented in a study phase, even when the item was not explicitly recollected.

[10] I would like to thank Peter Indefrey for this suggestion.

stimulus-response associations instead (Soldan, Habeck, Gazes, & Stern, 2010). The underlying mechanisms of repetition priming will be further discussed below, taking into account the electrophysiological results obtained in Experiment 1.

4.4.2 Modulations of ERP components

4.4.2.1 Early time windows (P1-N1 complex)

None of the behavioural effects were reflected in modulations of the early components P1 or N1 (up to 160 or 200ms depending on electrode site). The P1 and N1 component have been connected with early visual processing such as perception of spatial frequency or luminance as well as attentional processes such as shifting attention from one location to another (Johannes, Münte, Heinze, & Mangun, 1995; Vogel & Luck, 2000). These findings suggest that neither colour-diagnosticity nor repetition priming affected early perceptual processes or spatial allocation of attention (although see Chapter 4.4.2.2 for a discussion of how other types of attention can modulate the P2 component, which did show colour-diagnosticity and repetition priming effects). This finding is at odds with Experiment 0b, where colour-diagnosticity interacted with type of prime (colour box vs. checkerboard pattern) in this latency range. We interpreted this finding as reflecting a disadvantage in early visual recognition of HCD objects when presented in black and white. This disadvantage would not be present for LCD objects, which rely less on surface and colour information for identification (Laws & Hunter, 2006; Tanaka & Presnell, 1999). One possible explanation for the difference in findings between Experiment 0b and Experiment 1 is that in the present study, line drawings were used instead of photographs to achieve higher naming accuracy rates. The additional ease of recognition (by providing a clearer form with higher contrast between lines and background compared to an achromatic photograph) might have eliminated early perceptual disadvantages of HCD objects.

4.4.2.2 Effects of colour-diagnosticity and repetition priming on the P2

In Experiment 1, the P2 component was modulated by colour-diagnosticity (colour-diagnosticity effect, Figure 4-5) and block (repetition priming effect, Figure 4-6). In the case of repetition priming, faster reaction times on blocks 2 and 3 corresponded to a larger P2 amplitude, whereas high colour-diagnosticity resulted in slower reaction times and a larger P2 amplitude compared to low colour-diagnosticity (cf. Figure 4-3). The behavioural congruency effect was not reflected in modulations of the P2 component.

Regarding the effect of colour-diagnosticity, the results seem in accordance with previous findings by Costa et al. (2009), where low word frequency was reflected in longer reaction times and a more pronounced P2 component compared to high frequency words, suggesting that the P2 reflects difficulty of lexical access (see Redmann et al., 2014 for a discussion of Experiment 0b). In Experiment 1, high colour-diagnosticity resulted in longer reaction times and a more pronounced P2 component. This finding would suggest increased difficulty of lexical access for HCD objects compared to LCD objects. As discussed previously for the behavioural effect of colour-diagnosticity, this effect could be based on the fact that HCD stimuli presented in black-and-white are inherently more ambiguous in terms of shape than LCD objects, leading to a larger number of activated concepts, activating in turn a larger number of lexical competitors, thereby slowing down the process of determining the "winning" lemma during lexical access.

We also found a positive shift in the ERPs, starting in the P2 time window, for repeated stimuli compared to the first block. This repetition effect is in line with previous ERP studies on repetition priming of pictorial stimuli (for reviews, see Guillaume et al., 2009; Rugg, Soardi, & Doyle, 1995). Results from these studies suggest that stimulus repetition modulates the ERPs within a time window of approximately 200ms to 400ms, or even up to 600ms post stimulus presentation, with a maximum over parietal areas (Gruber

& Müller, 2002; Guillaume et al., 2009; Rugg et al., 1995). The positive shift of waveforms elicited by repeated items found in Experiment 1 starts at approximately 200ms and was also located mainly over parietal areas (see Figure 4-6), suggesting that it is in line with previous findings on how repetition priming modulated the ERPs.

The facilitatory effect of repetition priming found both behaviourally and in the P2 time range could thus reflect priming on one or multiple stages of processing the target pictures. As discussed above, repetition could reflect higher-level visual processing, lexical access or access to the phonological word form. If we consider the P2 component to reflect difficulty of lexical access, a repetition priming effect in this time range might suggest involvement in accessing the lemma. However, if we take the P2 component as reflecting difficulty of lexical access, the more pronounced P2 component for repeated items seems at odds with the presence of shorter reaction times for repeated items, given that shorter reaction times should correspond to easier, not more difficult lexical access.

These findings complicate the interpretation of the P2 component as an index of lexical access. Taking into account both the effects of colour-diagnosticity and the repetition priming, it seems problematic to assume a direct functional connection of reaction times and modulations of the P2 component. First, if that were the case, the P2 modulation based on stimulus repetition corresponded to faster reaction times, which is orthogonal to what we found for colour-diagnosticity. Second, we should also observe the congruency effect present in the reaction times as a modulation of the P2 amplitude. Thus, the increased P2 amplitude should not be readily interpreted as reflecting a detrimental effect on lexical access to the target picture's name (as was previously assumed in the interpretation of Experiment 0b, where we did not repeat items and thus had no way of investigating possible effects of repetition priming).

A very similar finding has been discussed by Strijkers et al. (2011): They replicated the frequency effect in the P2 time window, suggesting that it does reflect difficulty of lexical access (Costa et al., 2009; Strijkers et al., 2010), but extended the experimental paradigm to be able to analyse repetition effects as well. Corresponding to our results, they found a repetition effect starting in the P2 time window and extending over later time windows similar to the modulations found in Experiment 1. The authors argue that since the frequency effect was already present on the first presentation of the items, the repetition effect does not appear to be "responsible" for the presence of the frequency effect, and that the frequency effect seems to be "to some degree independent[ly] from processes directly associated with repetition, such as recollection" (Strijkers et al., 2011, pp. 351–352). This reasoning would also apply to Experiment 1 of the present dissertation, where an effect of colour-diagnosticity was already present on the first presentation. They also discuss the possibility that, given the repetition priming effect starting in the P2 time range, all positive shifts in this time window might indicate facilitated articulatory processes instead of lexical processing. However, since their results show different reaction time effects corresponding to a larger positivity in the P2 time range for repetition priming compared to frequency, the authors state that is likely that different underlying cognitive functions are reflected, and that the effect is not reducible to motor preparation. Furthermore, they found different scalp distributions for the repetition priming effect and the frequency effect, indicating different functional underpinnings. Their results regarding the frequency effect (low frequency word producing a larger P2 and longer reaction times) correspond to the larger P2 and longer reaction times found for HCD objects in the present study. Experiment 1 of the present thesis also showed some differences in topography between the two effects: The effect of colour-diagnosticity was more right-lateralised (starting in the P2 time window with a more pronounced lateralisation in later time windows) than the repetition priming effect.

Taking into account the above-named differences between the frequency and repetition effects in their study, Strijkers et al. (2011) conclude that the P2 effect of repetition could reflect "recollection of a previously seen item" (*p*. 9), whereas the frequency effect found in their study (which occurs at least to some degree independently of the repetition effect) reflects lexical processing. Following their argumentation, the colour-diagnosticity effect found in Experiment 1 seems to be independent from the repetition effect in two respects: 1) it corresponds to reaction time effects of a different polarity, and 2) it has a slightly different topography. Additionally, the effects are of different magnitudes, the repetition causing more pronounced modulations of the ERPs compared to the colour-diagnosticity effect. It could thus be argued that even though the two effects occur in the same time window, they reflect different (but possibly overlapping) underlying processes.

However, even though this line of reasoning uses the different findings in terms of reaction times for the two P2 effects as an argument for their discriminability, it cannot fully explain how these differences may arise: How can a more positive P2 correspond to slower reaction times in one case (colour-diagnosticity), and faster reaction times in the other (repetition priming)? The literature suggests that the P2 component reflects a variety of cognitive functions, such as reaction to stimulus properties, attention, working memory, and recall from memory. It is thus possible, and even likely, that more than one underlying cognitive function contributes to some extent to both the effect of colour-diagnosticity and the effect of repetition priming in this time window. The degree to which each underlying function has an impact might vary between the two effects (since there is some indication that they are not caused by identical sources as discussed above).

The underlying mechanisms and their proportions might thus differently influence net reaction times in the case of colour-diagnosticity on the one hand and repetition priming on the other hand.

Given that the P2 component reflects, among other processes, higher-level visual object perception (Cesarei et al., 2013), it is conceivable that colour-diagnosticity and repetition priming have similar consequences at the perceptual or conceptual stage of identifying the object as an instance of a given category (Francis, 2014). Repetition priming, on the one hand, facilitates recognition (and categorisation) of a given object, for instance via priming of its visual form and previous response to the object, especially in the case of identical repetition (as in Experiment 1). In the case of colour-diagnosticity, we discussed earlier that HCD objects tend to be more similar to each other in terms of shape than LCD objects (Laws & Hunter, 2006). This might allow them to be more readily categorised as an instance of a particular category (e.g., fruit, or natural object). Thus, facilitation at the stage of matching an objects visual form with a category stored in memory might be reflected in a more positive P2 component for repeated objects on the one hand, and HCD objects on the other hand. The reaction time difference could then be attributed to later processing stages, where high colour-diagnosticity results in increased competition at the lexical level based on propagation of activation from the conceptual level (as discussed above).

Attention could also be considered a common modulator for colour-diagnosticity and repetition priming (which is, however, difficult to reconcile with our results, as will be explained below). The possibility of attentional mechanisms modulating the P2 component is discussed by Strijkers et al. (2010):

> „It is possible that these P2 effects are indeed confounded by attention, with rare stimuli eliciting larger attentional shifts than more common stimuli (e.g., Luck and Hillyard

> 1994), but this would not take away the value of our observation because, in that case, these P2 differences most likely reflect attentional resources needed during lexical activation.“ (*p*. 926)

There might indeed be different attentional demands given greater structural similarity for HCD objects. More attentional resources could be needed to identify a shape that is similar to previously processed shapes, as would be the case with many HCD objects such as different kinds of round fruit. On the other hand, attentional demands should be lower for repeated items, novel stimuli requiring more attention (Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990; Luck & Hillyard, 1994). Following this line of reasoning, the P2 effects connected to high colour-diagnosticity and repetition should be dissimilar, whereas we found a more positive-going P2 for both HCD and repeated items. Therefore, attention seems to be less likely to play a common role for repetition priming and the colour-diagnosticity effect.

In summary, these considerations suggest that underlying functions other than lexical processing should be taken into account when interpreting the P2 component. The assumption of underlying perceptual or attentional mechanisms is in line with previous research connecting the P2 to visual feature detection (Luck & Hillyard, 1994), however, different attentional mechanisms in the case of high and low colour-diagnostic object are difficult to reconcile with the results obtained in Experiment 1. Therefore, the interpretation of the P2 component as an index of lexical access should be reconsidered. ERP components can often reflect the sum of multiple underlying components (Luck, 2005), which can be difficult to discriminate. Thus, the P2 component might reflect a mixture of higher-level perceptual and lexical processes, to be disentangled in further research.

4.4.2.3 Effects of colour-diagnosticity and repetition on the N300 and P3

Also the N300 was modulated by colour-diagnosticity: HCD objects showed a less negative amplitude than LCD objects. Given previous studies on the N300, the effect of colour-diagnosticity in this time window could reflect perceptual differences between the HCD and LCD stimulus groups. Schendan and Kutas (2003), for instance, showed that the N350 is sensitive to perceptual differences between visual stimuli, such as presentation in a canonical or non-canonical orientation. As mentioned above, HCD objects tend to have similar shapes, whereas LCD objects are more dissimilar, so an interpretation of the N300 in terms of perceptual processing would be in line with our results. The N300 has also been attributed to visual semantic processing (McPherson & Holcomb, 1999), such as the integration of shape and colour information (Bramão, Faísca et al., 2011; Lu et al., 2010). For instance, Lu et al. (2010) showed that the N300 was attenuated for typically coloured objects as opposed to atypically coloured or achromatic objects. This finding, however, would be at odds with results from Experiment 1, since the grey background on which the stimuli were presented could be a possible colour for most LCD, but not for most HCD objects. Therefore, the N300 should be attenuated for LCD items, not HCD items. Our findings are thus more difficult to integrate with differences in visual semantic processing.

We also found a significant effect of colour-diagnosticity in the P3 time range, HCD objects eliciting higher mean amplitudes than LCD objects. The P3 component has been connected to post-perceptual processing, including expectancy of events, with rare stimuli eliciting a larger P3 component (Donchin, 1981; Johnston & Holcomb, 1980, cf. Salti, Bar-Haim, & Lamy, 2012). Detection of rare events is unlikely to account for the effect of colour-diagnosticity in this time window, since the same number of different objects occurred equally often in the HCD and LCD conditions. While the P3 component has also been shown to be modulated by detection of differences in timing between experimental stimuli (Ernst et al., 2017), this explanation can be ruled out in our case, since trials for HCD and LCD stimuli were of equal length. According to Indefrey and Levelt (2004), the P3 falls within the time window of the retrieval of phonological features (250 to 330ms post stimulus onset). However, since linguistic stimulus dimensions such as phonological properties of the target words did not differ systematically between HCD and LCD objects, it does not seem likely that the P3 effect of colour-diagnosticity reflects differences in phonological processing. It should be noted that differences in the two latest time windows (N300 and P3) seem to be caused to a large extent by the positive shift that occurred earlier for HCD objects compared to LCD objects (P2 time window, see Figure 4-5). Effects in these time windows could thus reflect a continuation of the effect on the P2 and should be interpreted with caution.

4.4.3 Summary

To recapitulate, the main goal of Experiment 1 was to follow up on one of the central open questions raised by Experiment 0b: Could the lack of a facilitatory priming effect of a typical colour in Experiment 0b have been due to a mismatch between the colour presented before the picture and the representation in the object's frame? Our results support this hypothesis: Experiment 1 showed that colour distractors presented as colour words 400ms before target onset in fact facilitated naming of HCD objects. This result suggests that the lack of a similar congruency effect in Experiment 0b could indeed be due to choosing a wrong colour distractor not corresponding to the representation of its typical colour in the object's frame. Analysis of the ERPs, and in particular the P2 component did not provide further evidence as to whether the congruency effect in naming arises at perceptual, conceptual, lexical or subsequent levels of the word production process. Moreover, our results cast doubts on the interpretation of the P2 component as an index of lexical access, since a more positive P2 component was found in the presence of facilitation in the reaction times on the one hand (repetition priming effect), and behavioural interference on the other hand (colour-diagnosticity effect). To further investigate the time-course of the congruency effect and the processing stages affected by it in a behavioural paradigm, a follow up study (Experiment 2) modulated the timing of distractor presentation.

5 Experiment 2: The time course of colour congruency effects in naming

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 (-200ms), at the same time (SOA 0ms), and after the picture (SOA +200ms), thereby allowing a more complete picture of the dynamics of the colour congruency effect over time. This behavioural study was conducted with German native speakers, also allowing us to study generalisability of the congruency effect across languages.

5.1 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* – TOMATO; "red"), atypical colours (*braune* – TOMATE; "brown tomato"), unrelated adjectives (*leise* – TOMATE; "quiet tomato") or random letter strings (*nkfr* – TOMATE). To investigate the time course of congruency effects induced by colour distractors, we presented the distractors at three SOAs (-200ms, 0ms, +200ms). 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 -200ms would suggest that colour priming already affects perceptual or conceptual stages in naming the target. Facilitation effects at SOA 0ms would point to a later, lexical locus. Facilitation at an SOA of +200ms would suggest an effect of colour priming at a processing stage later than lemma access. In line with previous research, colour distractors should facilitate naming when presented at SOA -200ms, SOA 0ms, or both. We did not expect semantic effects to become effective at an SOA of +200ms. We also expected potential priming effects to only affect HCD objects (in line with the colour-diagnosticity hypothesis by Tanaka and Presnell, 1999). LCD objects should not benefit from co-activation of a colour adjective.

5.2 Methods

5.2.1 Participants

In total, 106 participants took part in the experiment (28 male and 78 female, mean age 23.51 years, *SD* = 5,06 years). 10 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.

5.2.2 Materials

Since Experiment 2 was conducted with German-speaking participants, we constructed a new set of HCD and LCD items similar to the one used in Experiment 1 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. We selected a subset of 228 pictures from the Snodgrass and Vanderwart picture set (Snodgrass and Vanderwart, 1980) and the picture database from the Max Planck Institute for Psycholinguistics in Nijmegen, Netherlands (these sets were also used for Experiment 1). Based on the pre-test conducted for Experiment 1, we defined HCD items as those items for which over 55% of the participants confirmed the existence of a typical colour (*M* = 86.4%) and agreed on that colour. LCD items were defined as items for which less than 45% (*Max* = 39%)

confirmed the existence of a typical colour (*M* = 15%). In total, 65 HCD and 65 LCD objects were included as experimental items in the experiment.

For each item, the dominant colour was determined by the number of times the colour was named as the first typical colour in the survey. This colour was chosen as typical colour distractor. For atypical colour distractors, typical colours were rotated across items, making sure that the atypical colour for a given item was not named in the presurvey survey as a typical colour of the object. 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"), weiß ("white"). A set of seven adjectives for the unrelated adjective condition was chosen from CELEX (Baayen, H. R. 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). The unrelated adjectives belonged to three semantic categories, so that each of them could be considered unrelated for a number of target items (sound: *laut/leise*, speed: *langsam/schnell*, configuration: *leer/steil/tief*). For the letter string condition, seven random letter strings were created (using the generator provided by Reed, 2002) out of a set of consonants (phonotactically valid syllables were avoided in order to prevent subjects 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, neutral 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 5-1).

Table 5-1. 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 (sum)
HCD	86.4	2.1	1.8	2.7	1.1	43
LCD	17.8	2.2	1.8	2.9	1.1	21

The experimental list that each participant was presented with was unique and constructed in the following way: We created four experimental lists, such that every item appeared equally often in all experimental conditions across subjects. 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 adjective, colour adjective and letter string appeared the same number of times (16) during the whole experiment. Every adjective and 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.

5.2.3 Procedure

Target pictures were presented on a computer screen at a size of 240x240 pixel (with 1028x768 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 (1000ms) and a random interval between 0 and 200ms in which a blank screen was shown. In the "SOA -200ms" group, the distractor appeared on the screen. After 200ms, the picture appeared in the background, and distractor and picture remained on the screen for 2000ms. In the "SOA 0ms" group, distractor and picture appeared at the same time and remained on screen for 2000ms. In the "SOA +200ms" group, the picture appeared first, and after 200ms, the distractor was presented on the picture. Picture and distractor remained on screen together for an additional 1800ms. There was a 1000ms 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 minutes.

5.2.4 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 (-200ms, 0ms, +200ms). 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 were defined as described for Experiment 1 (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"), naming at the wrong level of specificity ("Krankenschwester"/"Frau") or difficulty recognising the picture ("Pferdeschwanz").

5.3 Results

5.3.1 Reaction times

5.3.1.1 All SOAs

Mean reaction times at all SOAs are displayed in Figure 5-1. 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.

There was a trend towards a main effect of Colour-Diagnosticity ($\chi2(1) = 3.653$, $p = 0.056$): HCD objects were named more slowly than LCD objects by a mean value of 45ms. SOA did not significantly affect reaction times ($\chi2(2) = 1.070$, $p = 0.586$). We found no main effect of Distractor Type ($\chi2(3) = 0.903$, $p = 0.823$), no interaction between Colour-Diagnosticity and Distractor Type ($\chi2(3) = 3.457$, $p = 0.326$), or between Colour-Diagnosticity, Distractor Type and SOA ($\chi2(17) = 22.038$, $p = 0.1832$). To explore the specific predictions for the presence of congruency effects at the three different SOAs, we conducted further analyses for each SOA. [11]

[11] In the -200ms and +200ms condition, two subjects were erroneously presented with distractors at -150ms and +150ms. Analyses with and without these subjects showed the same overall results, with the following exceptions: At SOA -200ms, the significant difference between HCD objects in the typical colour and atypical colour condition did not reach significance when the subjects were excluded, but was still present as a trend in the same direction ($p = 0.07$). At SOA +200ms, the trend for main effect of colour-diagnosticity was not significant (p=.01) when the subjects were excluded.

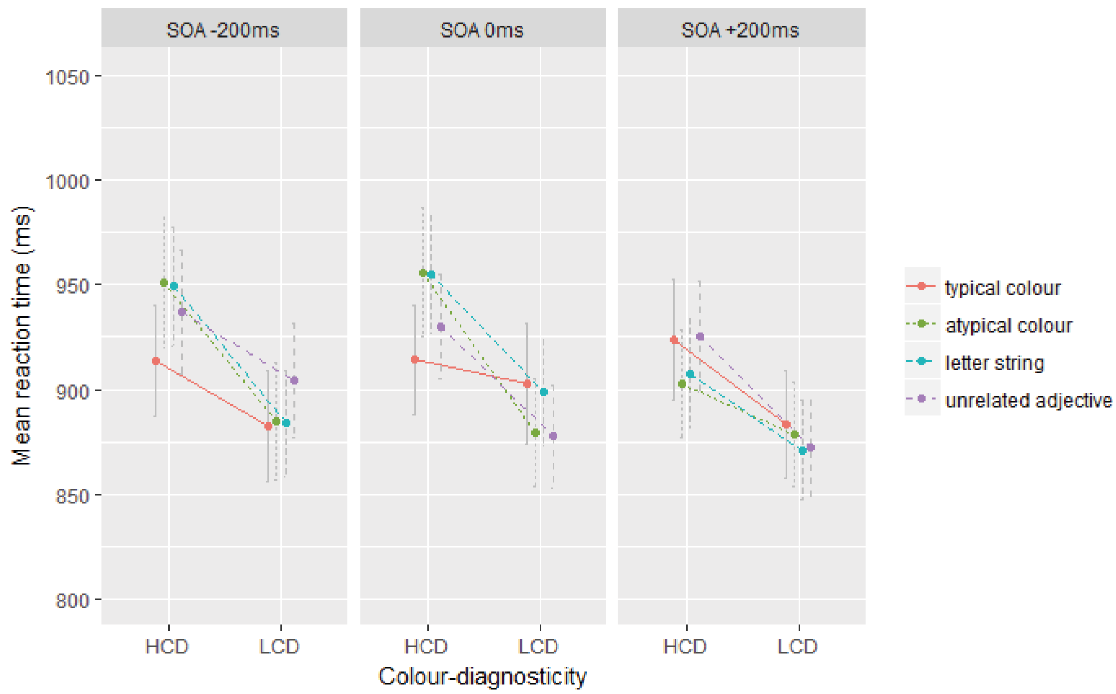

Figure 5-1. Mean reaction times in ms for high and low colour-diagnostic objects (HCD, LCD) paired with typical colour, atypical colour, unrelated adjective distractor, or letter string for the three stimulus onset asynchronies (SOA, -200ms, 0ms, +200ms) in Experiment 2. Error bars indicate 95% confidence intervals around the mean calculated using participants as id variable.

5.3.1.2 SOA -200ms

At SOA -200ms, the analysis yielded a trend for a main effect of Colour-Diagnosticity ($\chi 2(1)$ = 3.7421, p = 0.053).[12] 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 were significant ($t(3022.49)$ = -2.030, p = 0.021). HCD objects with a typical

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

colour distractor were named 37ms faster than when presented with an atypical colour distractor, and 35 ms faster than when presented with a letter string.

5.3.1.3 SOA 0ms

At SOA 0ms, there was a trend for a main effect of Colour-Diagnosticity ($\chi2(1)$ = 3.078, p = 0.079), HCD objects being named more slowly than LCD objects by 49ms. There was no effect of Distractor Type ($\chi2(3)$ = 1.108, p = 0.775). A trend towards a significant interaction between Colour-Diagnosticity and Distractor Type was found ($\chi2(3)$ = 7.695, p = 0.053).[13] 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). No other pairwise comparisons were significant.

5.3.1.4 SOA +200ms

The trend for a main effect of Colour-Diagnosticity found at SOA-200ms and SOA 0ms was also present at SOA+200ms ($\chi2(1)$ = 2.8132, p = 0.093): HCD objects were named significantly more slowly than LCD objects.[14] Again, we found no main effect of Distractor Type ($\chi2(3)$ = 4.214, p = 0.239). There was no significant interaction between Colour-Diagnosticity and Distractor Type ($\chi2(3)$ = 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 pairwise contrasts (all p > 0.05).

5.3.2 Error rates

Naming errors were analysed using generalised linear mixed models (GLMM) (with a binomial distribution) following the procedure outlined for Experiment 1.

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[13] This trend was significant when also including a by-subject random slope for Distractor Type ($\chi2(1)$= 7.979, p = 0.046).

[14] This trend, however, was not present with all possible random effects structures: When including Distractor Type as by subject-random slope, it was not significant ($\chi2(1)$ = 2.288, p = 0.130).

5.3.2.1 All SOAs

Generalised linear mixed models showed no main effect of Colour-Diagnosticity ($\chi2(1)$ = 2.6223, p = 0.105). However, the analysis yielded a main effect of SOA ($\chi2(2)$ = 1.0698, p = 0.586), post-hoc contrasts indicating that fewer errors were made at SOA +200ms compared to SOA -200ms (z = -2.576, p = 0.030) and SOA 0ms (z = -2.944, p = 0.010). There was no main effect of Distractor Type ($\chi2(3)$ = 1.788, p = 0.618), but a significant interaction between Colour-Diagnosticity and Distractor Type ($\chi2(3)$ = 8.828, p = 0.032), and a three-way interaction between Colour-Diagnosticity, Distractor Type and SOA ($\chi2(17)$ = 28.122, p = 0.043). To further explore this interaction, we turned to subanalyses per SOA to systematically examine the effects of interest.

5.3.2.2 SOA -200ms

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 ($\chi2(1)$ = 2.676, p = 0.102) or Distractor Type ($\chi2(3)$ = 2.396, p = 0.494), but a trend for an interaction between Colour-Diagnosticity and Distractor Type ($\chi2(3)$ = 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 = 0.034) or an unrelated adjective (z = -2.144, p = 0.032), whereas all other contrasts and post-hoc comparisons were non-significant (p > 0.05, see

Table5-2 for mean error rates).

5.3.2.3 SOA 0ms

There was no significant main effect of Colour-Diagnosticity at SOA 0ms ($\chi2(1) = 1.048$, $p = 0.306$) or Distractor Type ($\chi2(1) = 1.666$, $p = 0.645$). There was, however, a trend for an interaction between Colour-Diagnosticity and Distractor Type ($\chi2(3) = 7.315$, $p = 0.062$), which was not confirmed by contrasts and Bonferroni-corrected post-hoc tests (all $p > 0.05$).

5.3.2.4 SOA +200ms

There was a trend for a Colour-Diagnosticity effect at SOA+200 ($\chi2(1) = 2.744$, $p = 0.098$): HCD objects were named less accurately than LCD objects overall. No main effect of Distractor Type ($\chi2(3) = 6.139$, $p = 0.105$) and no interaction between Colour-Diagnosticity and Distractor Type ($\chi2(3) = 4.153$, $p = 0.245$) were found.

Table5-2. 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 -200ms	HCD	0.17	0.21	0.21	0.18
	LCD	0.15	0.14	0.13	0.16
SOA 0ms	HCD	0.18	0.19	0.20	0.21
	LCD	0.19	0.18	0.17	0.13
SOA +200ms	HCD	0.17	0.14	0.17	0.14
	LCD	0.14	0.11	0.10	0.11

5.4 Discussion

In accordance with results from Experiment 1, HCD objects were named more slowly across all SOAs. The same reasoning as detailed in Chapter 4.4.1.1 holds: This effect may be attributed to the fact that many HCD objects are natural kinds, as opposed to artificial objects, which tend to be LCD. Natural objects tend to be harder to name than man-made objects, which could be due to the higher degree of form-related resemblance among natural objects (e.g., different kinds of fruit that are all round and rely on differentiation from other, similar objects based on colour and texture, Laws & Hunter, 2006; Tanaka & Presnell, 1999).

Furthermore, 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 200ms 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, Segui, & Ferrand, 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 200ms). 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.

First, these results 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 200ms after the target picture. This finding was to be expected, since previous research indicates 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). The fact that we found a congruency effect when presenting the distractor 200ms before and at the same time as the target picture suggests that activation of the colour attribute influences production of the target word at a conceptual level (since colour was effective early in processing), and also at the lexical level (since the effects persisted until SOA 0ms).

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. These findings suggest that colour priming influences perceptual or conceptual as well as lexical processing. To further disentangle whether this effect is most influential for perceptual, conceptual or lexical processing of to-be-named picture, we decided to adopt the ERP paradigm used for Experiment 1, but changing the SOA from a longer negative SOA (-400ms) to 0ms. We collected EEG data in addition to reaction times and error rates to achieve additional insight into the time-course of naming the target picture, exceeding the information provided by net reaction times. Prior to this EEG study (Experiment 4), we conducted a behavioural pilot with identical materials and procedure (without the addition of EEG measurements, Experiment 3) to replicate the effect found with the German material in Experiment 2 with the original (Dutch) stimuli that were used in Experiment 1. In this way, we maximised comparability between effects of pre-activation of the colour attribute at SOA -400 (Experiment 1), and at SOA 0ms (Experiment 3 and 4).

6 Experiment 3: Activating typical colours at SOA 0ms

6.1 Design and objective

Experiment 3 consisted in a behavioural pilot for the EEG study planned as Experiment 4. Both experiments were identical in terms of stimulus material and procedure, varying only in the addition of EEG measurement in Experiment 4. In both experiments, we used the material and procedure employed in Experiment 1, to replicate with the Dutch stimulus material the congruency effect found at SOA 0ms with German material (Experiment 2). As for Experiment 2, we expected a colour-diagnosticity effect: Colour-diagnostic objects have been shown to be more difficult to name than LCD objects when presented without colour (Experiment 0a, 1; Tanaka & Presnell, 1999). Furthermore, we expected congruent colour distractors to facilitate naming of HCD objects compared to an atypical colour, whereas for low colour-diagnostic object, no difference between distractor types was expected.

6.2 Methods

6.2.1 Participants

Thirty-three healthy participants (25 female, 8 male; mean age = 23, *SD* = 3.05) took part in the study. Three of these participants were recorded as replacements for participants who were excluded from further analyses because of recording errors (2 participants), or because the participant wished to cancel the experiment due to fatigue (1 participant), resulting in 30 subjects included in the final analysis. All participants were not colour-blind and did not report any neurological disorders or dyslexia. Participants received course credit or money for participation.

6.2.2 Materials

The visual stimuli (line drawings and distractor words) used in this experiment were identical to the stimuli used in Experiment 1.

6.2.3 Procedure

The procedure and presentation of stimuli corresponded to the setup used in Experiment 1. Stimulus onset asynchrony was changed to 0ms, so that distractor and target picture were presented simultaneously. The timing of each trial was as follows: First, a fixation cross appeared and stayed on the screen for 2000ms. After that, a blank screen was presented for a random period of time between 400 and 600ms. Then, the target picture superimposed with the distractor word appeared on the screen with a duration of 2000ms. After 3000ms, the next trial started.

6.2.4 Data analysis

Reaction times and error rates were analysed using the same procedure as described for Experiment 1. As in Experiments 1 and 2, we used mixed linear models to analyse the reaction time data. For all mixed models, we included random intercepts for subject and item as well as random by-subject slopes for Colour-Diagnosticity and by-item slopes for Distractor Type besides the fixed effects of interest: Colour-Diagnosticity (HCD, LCD), Distractor Type (typical colour, atypical colour, unrelated adjective) and Block (1,2,3).

6.3 Results

Mean reaction times are displayed in Figure 6-1. Erroneous trials (defined as described for Experiment 1) were excluded from reaction time analyses (12,2%). Three items were excluded from further analyses because of high error rates (above 60%, 1 LCD, 2 HCD).

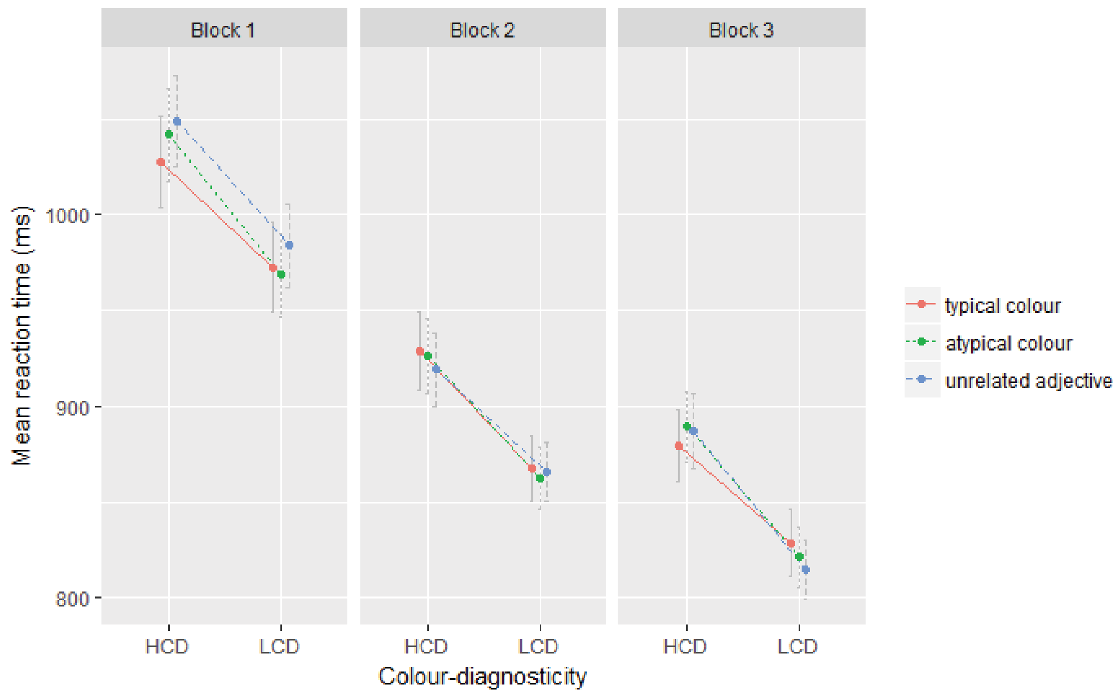

Figure 6-1. Mean reaction times in ms for high and low colour-diagnostic objects (HCD, LCD) paired with typical colour (TC), atypical colour (AC) or unrelated adjective distractor (UA) for the three blocks (1,2,3) in Experiment 3. Error bars indicate 95% confidence intervals around the mean calculated using participants as id variable.

6.3.1 Reaction times

There was a significant main effect of Colour-Diagnosticity ($\chi 2(1) = 12.378$, $p < 0.001$), showing that HCD objects were named more slowly than LCD objects by 62ms. We also found a main effect of Block ($\chi 2(2) = 1209.6$, $p < 0.001$). Naming latencies were on average 112ms faster on the second compared to the first block ($t(11472.89) = 24.316$, $p < 0.001$), and 42ms faster on the third compared to the second block ($t(11499.75) = 10.675$, $p < 0.001$). Again, there was no main effect of Distractor Type ($\chi 2(2) = 0.961$, $p = 0.619$). The interaction between Colour-Diagnosticity and Distractor Type was not significant ($\chi 2(2) = 0.855$, $p = 0.652$), nor was the interaction between Colour-Diagnosticity, Distractor Type and Block ($\chi 2(12) = 8.583$, $p = 0.738$). As for Experiment 1, separate analyses were conducted per block.

In the first block, there was a main effect of Colour-Diagnosticity ($\chi2(1) = 6.543$, $p = 0.010$), HCD objects were named more slowly than LCD objects. In addition to that, there was a significant main effect of Distractor Type ($\chi2(2) = 6.047$, $p = 0.049$), which was not confirmed in post-hoc comparisons (all $p > 0.05$). The analysis did not yield a significant interaction between Colour-Diagnosticity and Distractor Type ($\chi2(2) = 0.959$, $p = 0.619$), but contrasts revealed a significant difference between HCD objects presented with a typical colour and HCD objects presented with an unrelated adjective ($t(174\text{-}13) = -2.043$, $p = 0.021$). HCD objects were named on average 22ms faster with a typical colour distractor than with an unrelated adjective distractor. No other contrasts or Bonferroni-corrected post-hoc comparisons were significant. In the second block, the main effect of Colour-Diagnosticity found in the overall analysis was present as well ($\chi2(1) = 10.393$, $p = 0.001$). There was no main effect of Distractor Type ($\chi2(2) = 0.174$, $p = 0.917$), and no interaction between Colour-Diagnosticity and Distractor Type ($\chi2(2) = 0.308$, $p = 0.857$). Analysis of the third block yielded a main effect of Colour-Diagnosticity ($\chi2(1) = 15.901$, $p < 0.001$), no main effect of Distractor Type ($\chi2(2) = 0.454$, $p = 0.797$), an no interaction of Colour-Diagnosticity and Distractor Type ($\chi2(2) = 0.494$, $p = 0.781$). No contrasts or post-hoc comparisons were significant in the second and third block.

6.3.2 Error rates

Naming errors were analysed using generalised linear models as described for Experiment 1 (see Table 6-1 for mean error rates). There was no significant main effect of Colour-Diagnosticity ($\chi2(1) = 1.778$, $p = 0.183$) or of Distractor Type ($\chi2(2) = 0.177$, $p = 0.916$), and no interaction between Colour-Diagnosticity and Distractor Type ($\chi2(2) = 0.177$, $p = 0.916$), and no three-way interaction between Colour-Diagnosticity, Distractor Type and Block ($\chi2(12) = 7.165$, $p = 0.847$). We found a main effect of Block ($\chi2(2) =$

37.908, $p < 0.001$). Pairwise comparisons revealed that there were less errors on the second block compared to the first block ($z = -4.948$, $p < 0.001$). Error rates did not differ significantly between the second and third block ($z = -0.786$, $p = 1.000$). Separate analyses of the three blocks only did not reveal any significant main effects, interactions or contrasts (all $p > 0.05$).[15]

Table 6-1. 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 3.

		TC	AC	UA
First block	HCD	0.14	0.16	0.15
	LCD	0.12	0.11	0.12
Second block	HCD	0.11	0.11	0.12
	LCD	0.08	0.10	0.08
Third block	HCD	0.11	0.10	0.11
	LCD	0.09	0.07	0.10

6.4 Discussion

In Experiment 3, we again found a clear reaction time effect of colour-diagnosticity, in the form of HCD objects taking longer to name than LCD objects. We also replicated the finding that reaction times were faster the second and third time an item was named in the course of the experiment and more accurate after the first presentation.

As in Experiment 2, we found a priming effect for HCD objects paired with their typical colour compared to a neutral control stimulus in the first block.[16] As expected, no such priming effect was found for LCD objects. However, we did not replicate the finding of a colour congruency effect: Naming times for HCD objects did not benefit significantly from

[15] All models in the error analysis were carried out with a simplified random effects structure, omitting the by-item slope for Distractor Type, to enable convergence of the models.

[16] Note, however, that in Experiment 2, the priming effect consisted in a significant difference between typical colour distractors and a random letter string, not between typical colour and unrelated adjective, as in Experiment 3. Since we consider both to be a neutral condition compared to the typical colour, we will group both effects under „priming effect", acknowledging qualitative differences in processing for these two kinds of „neutral" stimuli. We believe this is admissible for the current set of studies, since the effect of interest is the congruency effect.

being paired with their typical colour compared to an atypical colour distractor. Thus, we only partly replicated the results from Experiment 2 with the Dutch stimuli used in Experiment 1. We will come back to this question in Chapter 8 for further discussion of the lack of a significant congruency effect and how it can be accounted for by taking into account different degrees of colour-diagnosticity.

Given the results from Experiments 2 and 3, there is some evidence that activation of a typical colour at SOA 0ms helps naming HCD objects. As became clear in Experiment 2, activation of the colour seems to affect conceptual processing and lexical processing, whereas an influence on a) only the lexical level, or b) on processing stages after lexical access is less likely. Since a beneficial effect of colour distractors on naming was found in Experiment 3 using the original stimuli employed in the Dutch PWI study presented as Experiment 1, we went on to conduct the next electrophysiological study (Experiment 4). In Experiment 4, we further explored the facilitation effect found behaviourally at SOA 0ms in Experiment 2 and Experiment 3. By introducing EEG signals as dependent variable in addition to reaction times and accuracy, we aimed to discern possible influences on earlier, perceptual or conceptual processing stages versus later, lexical processing stages.

7 Experiment 4: Activating typical colours at SOA 0ms: ERP study

7.1 Design and objective

Experiment 3 (in light of additional analyses described in Chapter 8) showed that the effect of colour congruency at SOA 0ms was present across languages: It was observed for German stimuli (Experiment 2) as well as Dutch stimuli (Experiments 3). However, behavioural results from these studies did not allow us to differentiate between different possible loci of the congruency effect in the process of naming the target picture. To gain further insight into the dynamics of the congruency effect found in Experiments 1 to 3, we conducted Experiment 4, which used the design and materials employed in Experiment 3 in combination with the collection of EEG signals. We expected to replicate the behavioural effects found in Experiment 3 (colour-diagnosticity effect, repetition effect). The analysis of ERP components could potentially reveal additional information on the time course of processing the target picture: If the P2 component can be interpreted as an index of lexical access (Costa et al., 2009; Strijkers et al., 2010; but see Chapter 4.4.2.2 for a discussion on the functional significance of the P2 component), we would expect an attenuated P2 component for HCD objects paired with typical colour distractors compared to atypical colour distractors, whereas no such difference should be observed for LCD objects.

7.2 Methods

7.2.1 Participants

32 participants (mean age 21.97 years (*SD* 3.13), 17 female, 15 male) took part in the experiment. One of these participants was measured as a replacement for another subject excluded from the final analyses because of a recording error; another participant did not finish the experiment due to fatigue and was likewise replaced with another participant,

resulting in a total of 30 participants included in further analyses. All remaining participants were right-handed native speakers of Dutch with normal or corrected-to-normal vision, no colour vision impairment and no reported neurophysiological deficits. They received study credit or money as a reward for participation.

7.2.2 Material

All stimulus materials used in this experiment corresponded to the ones used in Experiment 3.

7.2.3 Procedure

The experimental procedure and presentation of stimuli was identical to Experiment 3, except for the fact that we introduced another dependent variable by collecting EEG data in addition to measuring reaction times.

7.2.4 Analysis of reaction times and accuracy

Reaction times were analysed using linear mixed models as described for Experiment 1 (see Figure 7-1 for mean reaction times). Error rates were analysed following the procedure specified for Experiment 1 (12.4% of trials were excluded as errors, 4.6% because they were faster than 600ms). Two items were excluded because of high error rates (above 60%, 2 HCD items). As for Experiment 1, the random effects structure specified for the models below includes random intercepts for subject and item, as well as by-subject slopes for Colour-Diagnosticity and by-item slopes for Distractor Type. As predictors, Colour-Diagnosticity (HCD, LCD), Distractor Type (typical colour, atypical colour, unrelated adjective) and Block were included in the models.

7.2.5 EEG recording and analysis

As in Experiment 1, we recorded the EEG signal from 27 scalp electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, O2) and 3 facial electrodes (next to the left and right eye, and below the left eye) with the same apparatus and specifications as described for Experiment 1. Again, trials with voltages exceeding 100 μ, muscle or eye-blink artefacts were excluded from analysis (11% of all correct responses, range = 2-38% of correct responses per participant). A baseline correction (-200 to 0ms before onset of the target picture) was applied and averages per subject, electrode site and experimental condition were calculated. As in Experiment 1, repeated-measures ANOVA and Bonferroni-corrected post-hoc comparisons were used to test for the presence of main effects and interactions. The same factors as in Experiment 1 were entered into the ANOVA: Colour-Diagnosticity (HCD, LCD), Distractor Type (TC, AC, UA), Block (1,2,3), Anteriority (midline, frontal, posterior), and Laterality (central, left, right).

7.3 Results

7.3.1 Behavioural results

7.3.1.1 Reaction times

There was a significant main effect of Colour-Diagnosticity ($\chi 2(1) = 8.3226$, $p = 0.004$), HCD objects were named more slowly than LCD objects by 38ms. There was no main effect of Distractor Type ($\chi 2(2) = 5.0264$, $p = 0.051$). Block affected reaction times significantly ($\chi 2(2) = 744.31$, $p < 0.001$).

Reaction times on the first block were slower than on the second block ($t(10760.59) = 20.202$, $p < 0.001$), and reaction times on the third block were 26ms slower than on the second one ($t(10775.86) = 6.655$, $p < 0.001$).

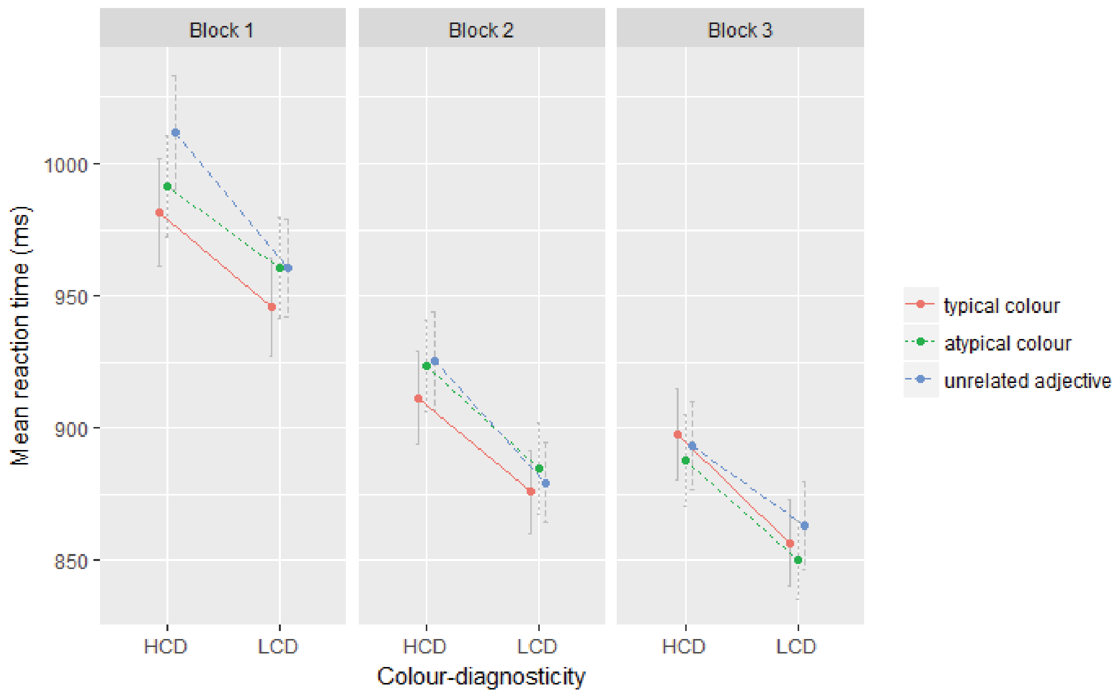

Figure 7-1. Mean reaction times in ms for high and low colour-diagnostic objects (HCD, LCD) paired with typical colour (TC), atypical colour (AC) or unrelated adjective distractor (UA) for the three blocks (1,2,3) in Experiment 4. Error bars indicate 95% confidence intervals around the mean calculated using participants as id variable.

The interaction of Colour-Diagnosticity and Distractor Type was not significant ($\chi2(2)$ = 0.070, p = 0.966), nor was the three-way interaction between Colour-Diagnosticity, Distractor Type and Block ($\chi2(12)$ = 10.319, p = 0.588). Separate analyses per block showed that in the first block, even though the interaction between Colour-Diagnosticity and Distractor Type was not significant ($\chi2(2)$ = 1.5665, p = 0.4569), HCD objects were named 26 ms faster with their typical colour as distractor compared to an unrelated adjective as revealed by contrast analyses ($t(135.57)$ = -2.628, p = 0.005). This contrast was also significant in the second block (t(3584.57) = -1.750, p = 0.040). No other contrasts or post-hoc comparisons were significant.

7.3.1.2 Error rates

Mean error rates are displayed in Table 7-1. There was no main effect of Colour-Diagnosticity on error rates ($\chi2(1)$ = 0.1345, p = 0.713), and no main effect of Distractor

Type ($\chi2(2) = 3.870$, $p = 0.145$). Block significantly affected error rates ($\chi2(2) = 124.17$, $p < 0.001$). There were significantly less naming errors on the second block compared to the first block ($z = -3.290$, $p < 0.003$), but there was no significant difference in error rates between the second and third repetition ($z = 1.447$, $p = 0.443$). There was no significant interaction between Colour-Diagnosticity and Distractor Type ($\chi2(2) = 0.341$, $p = 0.843$), and no three-way interaction between Colour-Diagnosticity, Distractor Type and Block ($\chi2(12) = 10.585$, $p = 0.565$). No contrasts or post-hoc comparisons were significant (all $p > 0.05$).

Table 7-1. 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 4.

		TC	AC	UA
First block	HCD	0.19	0.19	0.20
	LCD	0.20	0.17	0.19
Second block	HCD	0.17	0.14	0.15
	LCD	0.16	0.16	0.16
Third block	HCD	0.17	0.15	0.14
	LCD	0.19	0.19	0.17

7.3.2 Electrophysiological results

As in Experiment 1, there were differences in the sequence of peaks at posterior sites compared to frontal and central sites. At posterior sites, visual inspection showed peaks between 40 and 100ms (P1), 100 and 160ms (N1), 150 and 220ms (P2), 220 and 300ms (N300), as well as 300 and 380ms (P3) post picture onset. At frontal and central electrodes, there were peaks from 110 to 200ms, from 200 to 300ms, and from 300 to 380ms (which corresponded to the peak labelled P3 at posterior sites). Again, we used the time windows adapted to fit waveform morphology at posterior sites for the omnibus analysis. We conducted additional analyses at frontal and central electrode sites using the time windows adapted to these sites.

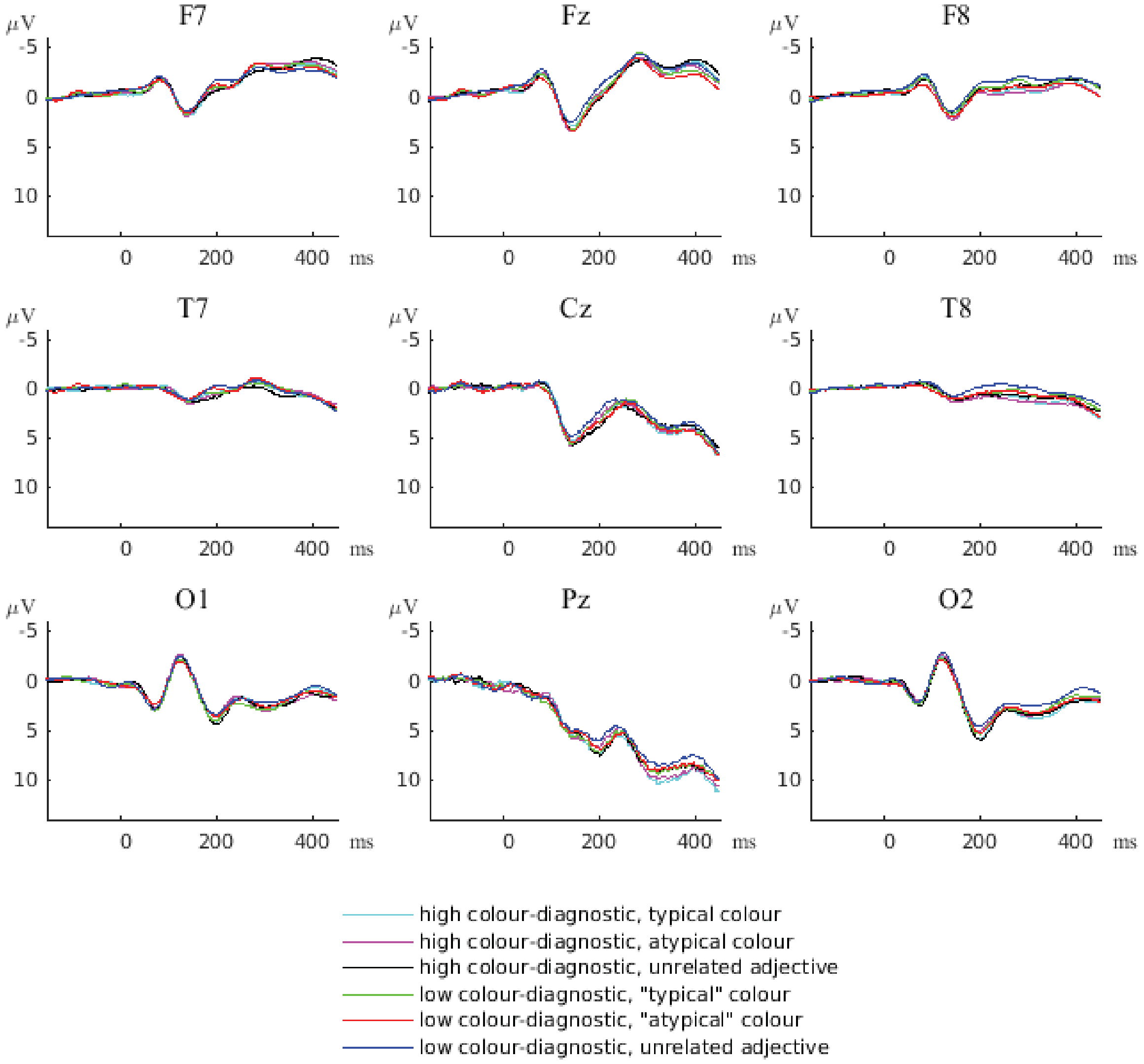

Figure 7-2. Grand-averaged amplitudes for high and low colour-diagnostic objects paired with typical colours, atypical colour, and unrelated adjectives at example electrodes in Experiment 4.

7.3.2.1 Omnibus analysis

40-100ms (P1)

In the earliest time window after stimulus presentation, we found no significant effects except for an interaction between Colour-Diagnosticity and Anteriority ($F(1.303,37.778) = 5.405$, $p = 0.018$, *pes* = 0.157). However, independent ANOVAs to further investigate the presence of a Colour-Diagnosticity effect at frontal, midline or posterior electrode sites remained nonsignificant (all $p > 0.05$).

100-160ms (N1)

In the 100 to 160ms time window, we found a significant effect of Block ($F(2,58) = 9.841$, $p = 0.001$, *pes* = 0.253). Bonferroni-corrected post-hoc comparisons revealed that the third block was significantly more positive than the first block ($p = 0.001$, *SE* = 0.257), and marginally more positive than the second block ($p = 0.060$, *SE* = .212). There was no significant difference between the first and second block ($p = 0.123$, *SE* = .266). In addition to this main effect, Block interacted with Anteriority ($F(2.373,68.806) = 4.294$, $p = 0.13$, *pes* = 0.129) and Laterality ($F(3.064,88.869) = 3.637$), $p = 0.015$, *pes* = 0.111).

Subsequent ANOVAs at all levels of Anteriority revealed that the effect of Block was significant at midline ($F(2,58) = 8.971$, $p < 0.001$, *pes* = 0.236), posterior electrodes ($F(2,58) = 14.237$, $p < 0.001$, *pes* = 0.329) and frontal electrodes ($F(2,58) = 4.035$, $p = 0.023$, *pes* = 0.122). At midline electrode sites, only the third block (*M* = 2.850, *SE* = 0.503) differed significantly from the first block (*M* = 1.785, *SE* = 0.454; $p = 0.001$, *SE* = 0.256), whereas all other comparisons were nonsignificant ($p > 0.05$). The same pattern was present at frontal electrodes, where only the third (*M* = 1.983, *SE* = 0.640) and first (*M* = 1.218, *SE* = 0.650) block differed significantly ($p = 0.039$, *SE* = 0.289, all other $p > 0.05$). At posterior electrodes, all blocks differed significantly from each other: The third block (*M* = 3.176, *SE* = 0.403) was more positive than the second (2.495, *SE* = 0.374; $p = 0.032$, *SE* = 0.249), and the second block more positive than the first (*M* = 1.731, *SE* = 0.320; p = 0.030, *SE* = 0.277).

Separate analyses for the different levels of Laterality showed that the effect of Block was present at central ($F(2,58)$ = 8.866, p = 0.001, *pes* = 0.234), left ($F(2,58)$ = 11.922, p < 0.001, *pes* = 0.291) and right electrode sites ($F(2,58)$ = 7.109, p = 0.002, *pes* = 0.197). At central electrode sites, only the third (*M* = 3.900, *SE* = 0.591) and the first block (*M* = 2.544, *SE* = 0.526) differed significantly (p = 0.001, *SE* = 0.145; all other p > 0.05). At left electrode sites, the third block (*M* = 2.240, *SE* = 0.349) differed from the second block (*M* = 1.677, *SE* = 0.370, p = 0.015, *SE* = 0.186), but there was no significant difference between the second and the first block (p = 0.094, *SE* = 0.236). Right electrode sites exhibited the same pattern as central electrode sites: Only the first (*M* = 1.049, *SE* = 0.327) and third block (*M* = 1.869, *SE* = 0.369) differed significantly (p = 0.002, *SE* = 0.218, all other p > 0.05). There were no other significant effects in this time window.

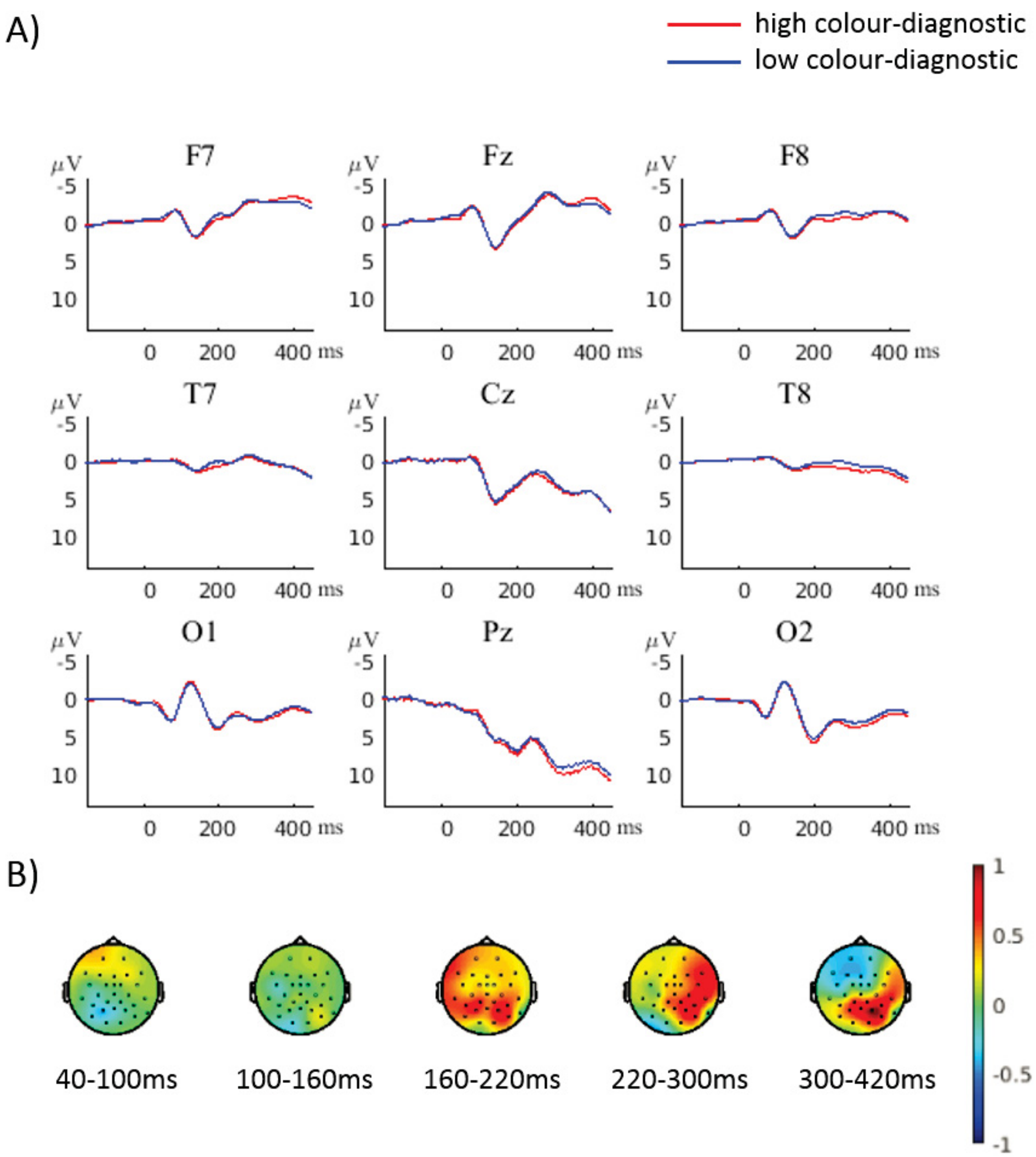

Figure 7-3. A) Grand-averaged amplitudes for high and low colour-diagnostic objects (HCD, LCD) at example electrodes in Experiment 4. B) Scalp topographies of difference between high and low colour-diagnostic objects across time windows.

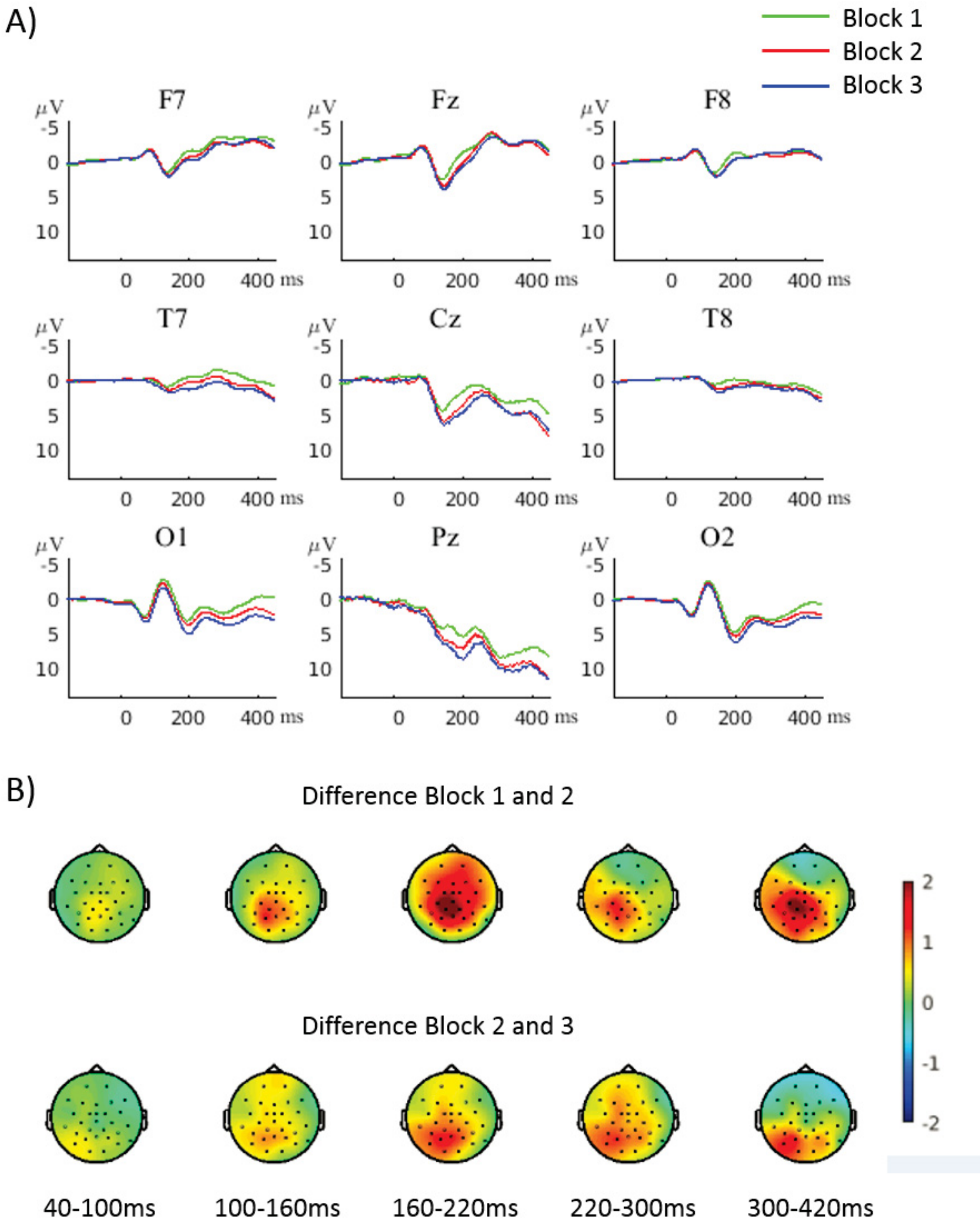

Figure 7-4. A) Grand-averaged amplitudes for Blocks 1, 2 and 3 at example electrodes in Experiment 4. B) Scalp topographies of difference between Block 1 and 2 and between Block 2 and 3 across time windows.

160-220ms (P2)

The repeated-measures ANOVA yielded a significant main effect of Colour-Diagnosticity in this time window ($F(1,29) = 6.965$, $p = 0.013$, *pes* = 0.194): HCD objects ($M = 3.169$, $SE = 0.431$) showed more positive mean amplitudes than low colour-diagnostic objects ($M = 2.762$, $SE = 0.432$, see Figure 7-3).

Furthermore, there was a significant main effect of Block ($F(2,58) = 31.185$, $p < 0.001$, *pes* = 0.518). Post-hoc tests (Bonferroni-correction) revealed that the second block ($M = 3.185$, $SE = 0.505$) was more positive than the first block ($M = 1.764$, $SE = 0.442$) ($p < 0.001$, $SE = 0.282$), and that the third block ($M = 3.931$, $SE = 0.410$) was in turn more positive than the second block ($p = 0.017$, $SE = 0.249$). Block interacted with Laterality ($F(4,116) = 12.363$, $p < 0.001$, *pes* = 299). There was an effect of Block at central electrode sites ($F(2,58) = 31.778$, $p < 0.001$, *pes* = 0.523), at left electrode sites ($F(2,58) = 28.553$, $p < 0.001$, *pes* = 0.496), and at right electrode sites ($F(2,58) = 25.858$, $p < 0.001$, *pes* = 0.471). Independent ANOVAs showed a significant effect of Block at central ($F(2,58) = 31.778$, $p < 0.001$, *pes* = 0.523), left ($F(2,58) = 28.554$, $p < 0.001$, *pes* = 0.496) and right electrode sites ($F(2,58) = 25.858$, $p < 0.001$, *pes* = 0.471). At central electrode sites, each block was significantly more positive than the preceding block: The third block ($M = 4.954$, $SE = 0.566$) differed from the second block ($M = 4.055$, $SE = 0.699$; $p = 0.027$, $SE = 0.321$), and the second block differed from the first block ($M = 2.221$, $SE = 0.673$; $p < 0.001$, $SE = 0.351$). The same pattern was present at left electrode sites, where the third block ($M = 3.253$, $SE = 0.386$) differed significantly from the second block ($M = 2.446$, $SE = 0.449$; $p = 0.003$, $SE = 0.221$), and the second block differed from the first block ($M = 1.206$, $SE = 0.382$; $p = 0.001$, $SE = 0.291$). At right electrode sites, there was a significant difference between the first and second block ($p < 0.001$, $SE = 0.237$), but not between the second and third block ($p = 0.79$, $SE = 0.228$).

The analysis yielded an interaction between Colour-Diagnosticity and Distractor Type ($F(2,58) = 0.041$, *pes* = 0.104). However, this effect did not become significant in Bonferroni-corrected post-hoc comparisons (all $p > 0.1$). There was no significant effect or trend indicating that HCD objects benefit from typical colour distractors compared to an atypical colour or unrelated adjective. There were no other significant main effects or interactions in this time window.

220-300ms (*N300)*

In this time window, we found a trend for a main effect of Colour-Diagnosticity ($F(1,29) = 3.835$, $p = 0.060$, *pes* = 0.117). As in the previous time window, HCD objects ($M = 1.864$, $SE = 0.497$) exhibited more positive amplitudes than LCD objects ($M = 1.479$, $SE = 0.472$). Colour-Diagnosticity interacted with Laterality ($F(2,58) = 7.030$, $p = 0.002$, *pes* = 0.195). The effect did not become significant at central ($F(1,29) = 2.617$, $p = 0.117$, *pes* = 0.083) and left electrode sites ($F(1,29) = 0.482$, $p = 0.493$, *pes* = 0.016). However, there was a significant main effect of Colour-Diagnosticity over right electrode sites ($F(1,29) = 13.967$, $p = 0.001$, *pes* = 0.325). Here, waveforms for HCD objects ($M = 2.198$, $SE = 0.473$) were more positive than LCD objects ($M = 1.591$, $SE = 0.447$).

Again, we found a main effect of Block ($F(2,58) = 8.633$, $p = 0.001$, *pes* = 0.229), and an interaction of Block with Anteriority ($F(1.891,54.836) = 4.123$, $p = 0.023$, *pes* = 0.124) and with Laterality ($F(4,116) = 5.595$, $p < 0.001$, *pes* = 0.162). To follow up on the interaction of Block and Anteriority, we conducted separate analyses for the different levels of Anteriority. These analyses revealed that the effect of Block was only present at midline ($F(2,58) = 8.632$, $p = 0.001$, *pes* = 0.229) and posterior sites ($F(2,58) = 16.990$, $p < 0.001$, *pes* = 0.369), whereas it was nonsignificant at frontal sites ($F(2,58) = 2.644$, $p = 0.080$, *pes* = 0.084). Post-hoc comparisons revealed that at midline electrode sites, the third block ($M = 2.120$, $SE = 0.543$) was significantly more positive than the second ($M = 1.410$, $SE =$

0.550; $p = 0.047$, $SE = 0.276$) and first block ($M = 0.685$, $SE = 0.472$; $p = 0.003$, $SE = 0.392$), whereas there was no difference between the first and second block ($p = 0.155$, $SE = 0.357$). Independent analyses at all levels of Laterality showed that the effect of Block was present at central electrode sites ($F(2,58) = 7.336$, $p = 0.001$, $pes = 0.202$), at left electrode sites ($F(2,58) = 12.742$, $p < 0.001$, $pes = 0.305$), and at right electrode sites, where the effect was slightly smaller ($F(2,58) = 4.684$, $p = 0.013$, $pes = 0.139$). Post-hoc comparisons showed that at central electrodes, the third block ($M = 2.818$, $SE = 0.694$) was significantly more positive than the first block ($M = 1.296$, $SE = 0.634$; $p = 0.005$, $SE = 0.338$), whereas there was no significant difference between the first and second ($M = 2.025$, $SE = 0.693$), or second and third block (all $p > 0.05$). At left electrodes, the third block ($M = 1.911$, $SE = 0.481$) was more positive than the first block ($M = 0.254$, $SE = 0.401$) and the second block ($M = 1.057$, $SE = 0.493$; $p = 0.004$, $SE = 0.242$). There was no significant difference between the first and second block ($p = 0.095$, $SE = 0.356$). At right electrodes, the only significant difference was found between the first ($M = 1.496$, $SE = 0.471$) and third block ($M = 2.375$, $SE = 0.479$; $p = 0.032$, $SE = 0.312$), whereas no other comparison was significant (all $p > 0.05$).

There was a three-way interaction between Colour-Diagnosticity, Block and Laterality ($F(4,116) = 2.534$, $p = 0.044$, $pes = 0.080$), but the effect disappeared in follow up analyses at the different levels of Laterality, which showed no significant interaction between Colour-Diagnosticity and Block (all $p > 0.05$). No other main effects or interactions were significant in this time window.

300-420ms (P3)

There was no main effect of Colour-Diagnosticity in this time window ($F(1,29) = 1.419$, $p = 0.243$, $pes = 0.047$), but Colour-Diagnosticity interacted significantly with Anteriority ($F(1.259,36.520) = 19.454$, $p < 0.001$, $pes = 0.401$) and Laterality ($F(2,58) = 3.563$, $p =$

0.035, *pes* = 0.109). Independent analyses at the different levels of Anteriority revealed that the effect was only present at posterior electrodes ($F(1,29)$ = 9.445, *p* = 0.005, *pes* = 0.246), where HCD objects (*M* = 6.715, *SE* = 0.648) showed more positive waveforms than LCD objects (*M* = 6.060, *SE* = 0.657). At central ($F(1,29)$ = 1.151, *p* = 292, *p*-0.038) and frontal electrodes ($F(1,29)$ = 0.792, *p* = 0.381, *pes* = 0.027), the effect was not significant. Further investigation of the interaction between Colour-Diagnosticity and Laterality revealed that, as in the previous time window, the effect of Colour-Diagnosticity was only present at right electrode sites ($F(1,29)$ = 5.997, *p* = 0.021, *pes* = 0.171), whereas it was nonsignificant and central ($F(1,29)$ = 0.724, *p* = 0.402, *pes* = 0.024) and left electrode sites ($F(1,29)$ = 0.095, *p* = 0.860, *pes* = 0.003). Where the effect was present, waveforms for HCD objects (*M* = 2.566, *SE* = 0.623) exhibited a more positive amplitude than LCD objects (*M* = 2.146, *SE* = 0.629).

Again, there was a main effect of Block ($F(2,58)$ = 5.681, *p* = 0.006, *pes* = 0.164), and an interaction of Block and Anteriority ($F(1.763,51.124)$ = 10.897, $p < 0.001$, *pes* = 0.273) and Laterality ($F(4,116)$ = 5.970, $p < 0.001$, *pes* = 0.171). Follow up analyses on the interaction of Block and Anteriority showed an effect of Block at midline electrode sites ($F(2,58)$ = 6.879, *p* = 0.002, *pes* = 0.192) and posterior electrode sites ($F(2,58)$ = 21.891, $p < 0.001$, *pes* = 0.430), whereas no effect of Block was present at frontal electrode sites ($F(2,58)$ = 0.410,*p* = 0.666, *pes* = 0.014). At midline electrode sites, the second block (*M* = 3.159, *SE* = 0.791) was more positive than the first block (*M* = 1.880, *SE* = 0.743; *p* = 0.019, *SE* = 0.435). The third block (*M* = 3.410, *SE* = 0.743) was more positive than the first block (*p* = 0.020, *SE* = 0.523), whereas there was no significant difference between the second and third block. At posterior electrodes, each block was more positive than the preceding block: There was a significant difference between the second (*M* = 6.600, *SE* = 0.705) and first block (*M* = 5.201, *SE* = 0.584; *p* = 0.001, *SE* = 0.341), and between the second and third block (*M* = 7.361, *SE* = 0.717; *p* = 0.045, *SE* = 0.294). Separate analyses at the levels of Laterality showed that the effect of Block was only present at central ($F(2,58) = 5.267$, $p = 0.008$, *pes* = 0.154) and left electrode sites, but not at right sites. At central electrodes, the second and third block were more positive than the first one: There were significant differences between the first (*M* = 2.863, *SE* = 0.811) and second (*M* = 4.182, *SE* = 0.918; *p* = 0.036, *SE* = 0.492), and between the first and third block (*M* = 4.313, *SE* = 0.885; trend *p* = 0.051, *SE* = 0.573).

There was an interaction between Distractor Type and Laterality ($F(4,116) = 3.255$, $p = 0.014$, *pes* = 0.101). Follow up independent ANOVAs revealed an effect of Distractor Type at right ($F(2,58) = 3.676$, $p = 0.031$, *pes* = 0.112), but not at central ($F(2,58) = 2.760$, $p = 0.072$, *pes* = 0.087) or left electrodes ($F(2,58) = 0.372$, $p = 0.691$, *pes* = 0.013). However, Bonferroni-corrected post-hoc comparisons at right electrode sites did not reveal any significant differences between distractor types (all $p > 0.05$).

7.3.2.2 Summary of electrophysiological results

As in Experiment 1, there were no effects of Colour-Diagnosticity, Distractor Type or Block in the earliest time window (P1). Starting in the N1 time window, we found a significant effect of Block, each repetition generally eliciting more positive waveforms than the previous ones (with slight variations as to which of the three blocks differed significantly from each other depending on electrode site). This large effect of Block lasted throughout the following time windows (P2, N300, P3) over midline and posterior electrode sites. Replicating the results found in Experiment 0b and Experiment 1, waveforms for HCD objects showed a more positive P2 component than LCD objects on midline and posterior electrode sites. The effect continued to be significant over posterior electrodes in the last time window (P3). Again, we did not find evidence for a modulation of the P2 component according to congruency of distractor and target object, since there was no interaction between Colour-Diagnosticity and Distractor Type in the P2 time window or any of the other time windows.

7.4 Discussion

7.4.1 Behavioural results

7.4.1.1 Colour-diagnosticity

The analysis of reaction times yielded a significant effect of Colour-Diagnosticity: HCD objects were named more slowly than LCD objects. This result replicates earlier findings from Experiments 1 to 3 and other studies in the literature (e.g., Tanaka & Presnell, 1999; Therriault et al., 2009). Possible reasons for the detrimental effect of Colour-Diagnosticity as described for Experiments 1 to 3 apply, and will be further discussed in Chapter 9 (General discussion).

7.4.1.2 Congruency effect

Even though there was a facilitatory effect of typical colours for HCD objects in this experiment, we did not find a congruency effect showing a facilitation compared to atypical colours as observed in Experiments 1 and 2. Instead, HCD objects presented with typical colours were named significantly faster than when presented with unrelated adjectives. As will be discussed in Chapter 8, the degree of colour-diagnosticity exhibited by the stimuli might explain the lack of a significant congruency effect in this experiment.

7.4.1.3 Repetition priming

As expected, we found a significant effect of Block in the reaction times and error rates, showing that participants made faster responses and fewer naming errors with each subsequent presentation of an item. Possible reasons for this repetition priming effect as discussed in Chapter 4.4 apply.

7.4.2 Modulations of ERP components

7.4.2.1 Early time windows (P1/N1)

As in Experiment 1, there was no modulation of the earliest component (P1) by either colour-diagnosticity, the congruency effect or repetition priming. However, in Experiment 4, the analysis revealed an early modulation of the ERPs starting in the N1 time window connected to repetition priming: There was a positive shift for repeated items compared to the first presentation. Possible reasons for this earlier onset of the repetition priming effect compared to Experiment 1 will be discussed below.

7.4.2.2 Effects of colour-diagnosticity and repetition priming on the P2

As in Experiment 1, we found an effect of colour-diagnosticity in the P2 time window: HCD objects showed a larger P2 amplitude than LCD objects. As in Experiment 1, this difference had its onset in the P2 time window, where it was present mainly over parietal regions, and became more right-lateralised in later time windows (see Figure 7-3). We also replicated the repetition priming effect found in Experiment 1, which was reflected in shorter response time and more positive ERP waveforms for repeated stimuli (see Figure 7-4).

Notably, the repetition priming effect did not only start earlier in Experiment 4 compared to Experiment 1, but also revealed significant differences between all blocks. In Experiment 1, we found that repetition priming was present only when comparing the first and second block, but no difference was found between the second and third block, and that the effect had a later onset compared to Experiment 4. One possible reason for this difference lies in the only design difference between the two experiments: The manipulation of SOA between distractor and target. In Experiment 1, distractors were presented 400ms before picture onset and disappeared 200ms before the picture. In Experiment 4, distractors were superimposed upon the picture, appeared simultaneously with it and lasted until the picture presentation period had elapsed. Thus, repetition priming effects caused by the distractor word should also modulate the ERP components following picture (and, incidentally, distractor) onset (for a review on repetition priming in word reading, see Brown, Roberts, & Besner, 2001). Previous ERP studies have found modulations of the ERPs as a function of (identical) word repetition in the N400 time range (for a review, see Kutas & Federmeier, 2011) and in the form of a positive deflection as early as 150ms after stimulus onset (Grainger & Holcomb, 2009; Holcomb & Grainger, 2006). Holcomb and Grainger (2006) interpret this early modulation of the ERPs as reflecting processing of visual features of the word. It is thus conceivable that there might be a repetition effect of the distractor word on top of the repetition effect of the target picture. This repetition priming effect might be particularly strong in this study compared to Experiment 1, since there was a much smaller set of distractor words than of pictorial stimuli.

Similar to the results observed in Experiment 1, we found different behavioural responses, but similar modulation of the P2 component as a function of a) colour-diagnosticity, and b) repetition priming. These findings further confirm that the interpretation of the P2 component as an index of lexical access should be revisited as discussed in Chapter 4.4.

7.4.2.3 Effects of colour-diagnosticity and repetition priming on the N300 and P3

As in Experiment 1, we found effects of colour-diagnosticity and repetition priming also in the later time windows (N300 and P3). As has been discussed in Chapter 4.4.2.3, it is possible that these later modulations reflect differences in perceptual processing or integration of visual object characteristics with stored representations. However, these components should be interpreted with caution since the significant effect found in these time windows might represent a general positive shift for HCD and repeated items starting in the P2 time window, instead of an additional modulation in the P3 time window (Luck, 2005; see Figure 7-3).

7.4.2.4 Summary

In summary, Experiment 4 replicated findings from Experiment 3 showing that colour distractors facilitated naming of high, but not of LCD objects. However, this effect was only visible when analysing behavioural data, whereas it was not reflected in the ERPs. Specifically, it was not reflected in the P2 component.

We also replicated results from Experiment 1, showing that even though colour-diagnosticity and repetition priming both affect the P2 component in the same directions, they modulate reaction times orthogonally: Whereas high colour-diagnosticity resulted in longer reaction times, the repetition priming effect was facilitatory. As has been argued in Chapter 4.4.2.2, these findings are problematic for interpreting the P2 component as an index of lexical access, and support the notion that additional underlying cognitive functions modulate the ERPs in this time window.

Importantly, there was a difference in findings between Experiments 1 and 2, on the one hand, and 3 and 4, on the other hand: In Experiments 1 and 2, typical colour distractors facilitated naming compared to atypical colour distractors (congruency effect), whereas in Experiments 3 and 4, the difference between these two conditions was not significant. Instead, typical colours facilitated naming compared to an unrelated adjective. A series of correlation analyses discussed in Chapter 8 could resolve this apparent discrepancy by relating the size of the congruency effect to the degree of colour-diagnosticity exhibited by the HCD objects used as stimuli in these studies.

8 Revisiting colour-diagnosticity and the congruency effect

Our analysis of Experiments 1 to 4 showed an apparent discrepancy between findings: We observed a congruency effect (i.e., faster naming latencies for HCD objects presented with typical colours compared to atypical colours) in Experiment 1 and 2, whereas there the congruency effect was not significant in Experiment 3 and 4 (in these Experiments, there was a priming effect in the sense that HCD objects were named faster when presented with a typical colour compared to an unrelated adjective).

One possible cause for this discrepancy could lie in the stimulus material used: We used a similar, but adjusted stimulus set in the experiment conducted in German (Experiment 2), which overlapped only party with the stimulus material for the experiments conducted in Dutch (Experiments 1, 3 and 4, 41% overlap). Results from our pre-study and other studies in the literature suggest that colour-diagnosticity is a graded phenomenon: Among the group of objects judged by a majority of participants to have a typical colour (i.e., which would be grouped as HCD), it is possible to construct a scale of colour-diagnosticity based on the strength of association with a typical colour and the number of possible typical colours that were associated with the object. It is possible that the degree of colour-diagnosticity mediates the size of a potential colour congruency effect. To this end, we conducted correlation analyses between the size of the congruency effect and the degree of colour-diagnosticity exhibited by each of the presented pictures.

8.1 Additional correlation analyses

To take into account the more nuanced notion of colour-diagnosticity described above and quantify the degree of colour-diagnosticity for each object in a continuous manner instead of as binary categories (HCD vs. LCD), we calculated the following colour-diagnosticity measures based on the pre-study conducted for Experiment 1: 1)

Percentage of subjects that answered “yes” to the question whether the object has a typical colour, 2) Colour diagnosticity score of dominant colour per item, 3) Difference between colour-diagnosticity score of dominant colour and colour-diagnosticity score of second-to-dominant colour. Colour diagnosticity scores for each item were calculated in the following way:

$$Score(i,c) = \max \sum_{i+1}^{n} \begin{matrix} 5\ points\ if\ c\ named\ as\ 1st\ colour \\ 4\ points\ if\ c\ named\ as\ 2nd\ colour \\ \vdots \\ 1\ point\ if\ c\ named\ as\ 5th\ colour \end{matrix}$$

where i is a given target picture, c is a given colour and n is the total number of participants. This colour-diagnosticity score takes into account not only each participant’s subjective opinion on whether an item has a typical colour or not, but also how often and how closely this colour was associated with the item across subjects. Table 8-1 illustrates that none of these measures differed between Experiments 1, 3 and 4 (Dutch stimuli) on the one hand and Experiment 2 (German stimuli) on the other hand.

Table 8-1. Mean colour-diagnosticity scores (SD) for Experiments 1 through 4 (reaction times to high colour-diagnostic objects with typical colour distractor minus reaction times to atypical colour distractor).

	Exp. 1,3,4	Exp. 2
HCD %	86.6 (10.1)	86.4 (10.5)
Score 1st colour	82.2 (20.9)	83.2 (23.3)
Score 1st colour minus second colour	69.9 (29.8)	65.2 (33.8)

We calculated Pearson-product-momentum correlations between the size of the congruency effect per item in ms (difference between mean reaction times in the HCD/typical colour condition and the HCD/atypical colour condition) for Experiments 1 to 4. For Experiments 1, 3 and 4, the analysis was limited to the first block to be able to compare the results with Experiment 2, in which there was only a single presentation of each item. We expected a positive linear correlation between the size of the congruency effect and the degree of colour-diagnosticity as indicated by the three colour-diagnosticity measures described above. One-sided *p*-values are reported throughout all analyses, since we expected a positive linear correlation.

8.2 Results

8.2.1 Experiment 1: Dutch PWI, SOA-400 (EEG study)

In Experiment 1, there was no significant correlation between the size of the congruency effect and colour-diagnosticity measured as percentage of positive HCD judgments ($r = -0.102$, $p = 0.802$). There was also no correlation between the size of the congruency effect and colour-diagnosticity measured as score of the dominant colour ($r = -0.039$, $p = 0.625$), nor between the size of the congruency effect and colour-diagnosticity measured as score of the dominant colour minus the second-to-dominant colour ($r = 0.067$, $p = 0.289$).

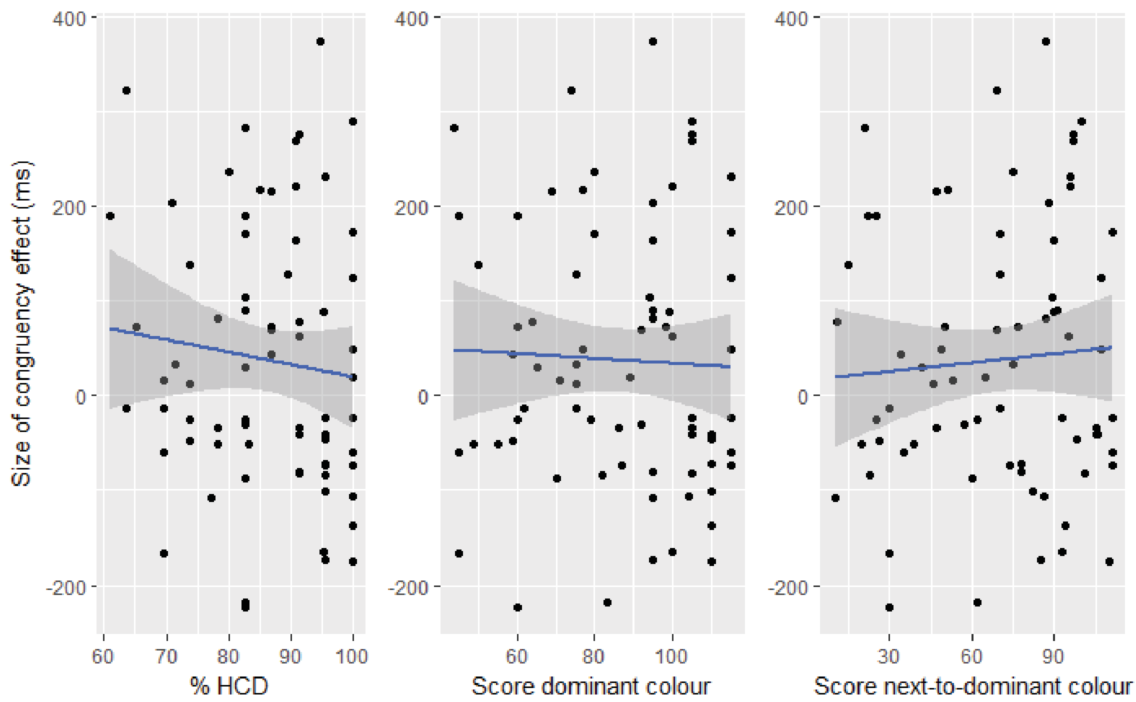

Figure 8-1. Correlations between size of congruency effect in ms and colour-diagnosticity of high colour-diagnostic (HCD) item as measured by a) percentage of subjects rating item as HCD (left column), b) score of the dominant colour (middle), and c) score of the next-to-dominant colour (right) in Experiment 1.

8.2.2 Experiment 2: German PWI, SOA-200, 0 and +200

There was no significant correlation between the size of the congruency effect and colour-diagnosticity measured as percentage of positive HCD judgments (r = 0.039, p = 0.382), colour-diagnosticity measured as score of the dominant colour (r= -0.167, p = 0.199), or colour-diagnosticity measured as score of the dominant colour minus the second-to-dominant colour (r= -0.195, p = 0.934). Looking at the three SOAs separately, there was no correlation between congruency effect size and HCD percentage (r= 0.066, p = 0.308), score of the dominant colour (r= -0.155, p = 0.234), or score of the dominant colour minus the second-to-dominant colour (r= -0.204, p = 0.942) at SOA -200ms. Correspondingly, at SOA 0ms, there was no correlation between congruency effect size and HCD percentage (r= -0.145, p = 0.868), score of the dominant colour (r= -0.233, p = 0.070), or score of the dominant colour minus the second-to-dominant colour (r= -0.231, p = 0.963). At SOA

+200ms, the correlation between congruency effect size and HCD percentage became significant (r= 0.230, p = 0.037). However, correlations between congruency effect size and score of the dominant colour (r= -0.020, p = 0.586), or score of the dominant colour minus the second-to-dominant colour (r= 0.120, p = 0.178) were nonsignificant.

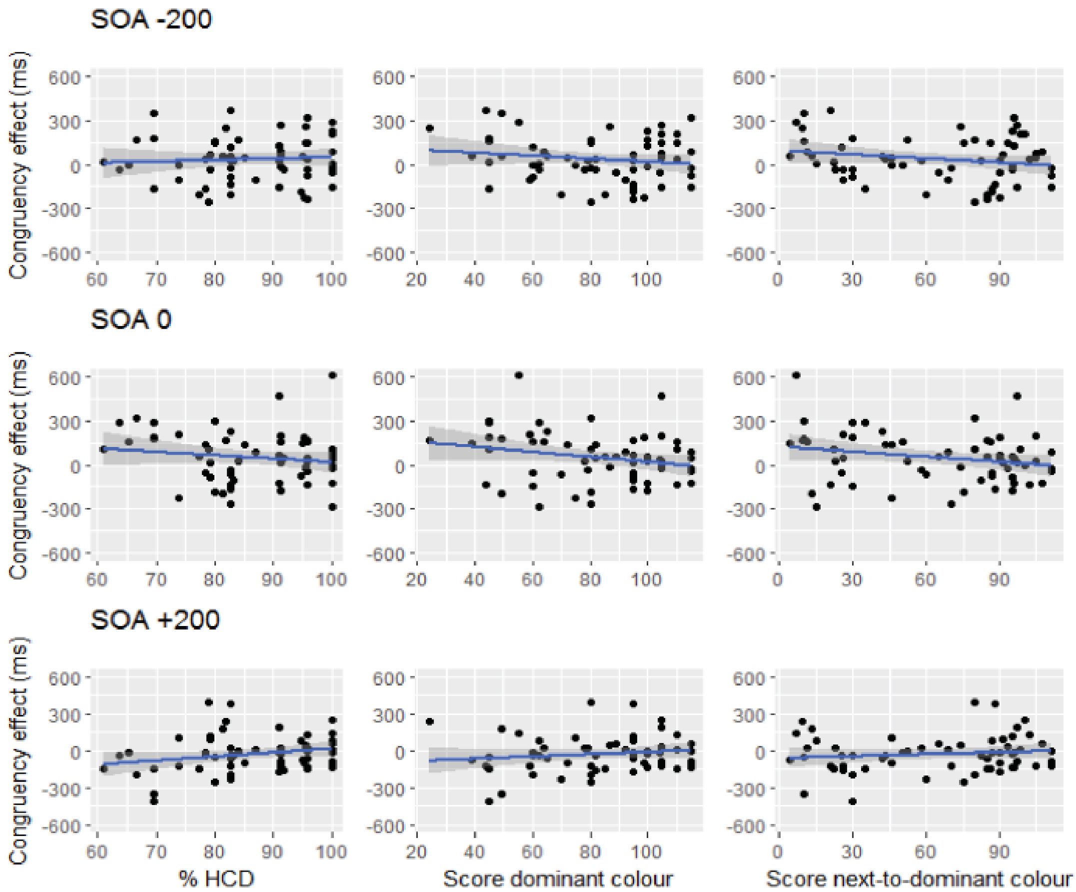

Figure 8-2. Correlations between size of congruency effect in ms and colour-diagnosticity of high colour-diagnostic (HCD) item as measured by a) percentage of subjects rating item as HCD (left column), b) score of the dominant colour (middle), and c) score of the next-to-dominant colour (right) at the three stimulus onset asynchronies (SOAs) used in Experiment 2.

8.2.3 Experiment 3: Dutch PWI, SOA 0ms (only behavioural)

In Experiment 3, the size of the congruency effect and percentage of positive HCD judgments were correlated (r = 0.251, p = 0.015). The correlation between congruency effect size and colour-diagnosticity measures as score of the dominant colour was also significant (r = 0.229, p = 0.024). These results were confirmed when analysing the correlation between congruency effect size and colour-diagnosticity score of the dominant colour minus second-to-dominant colour ($r = 0.267$, $p = 0.010$).

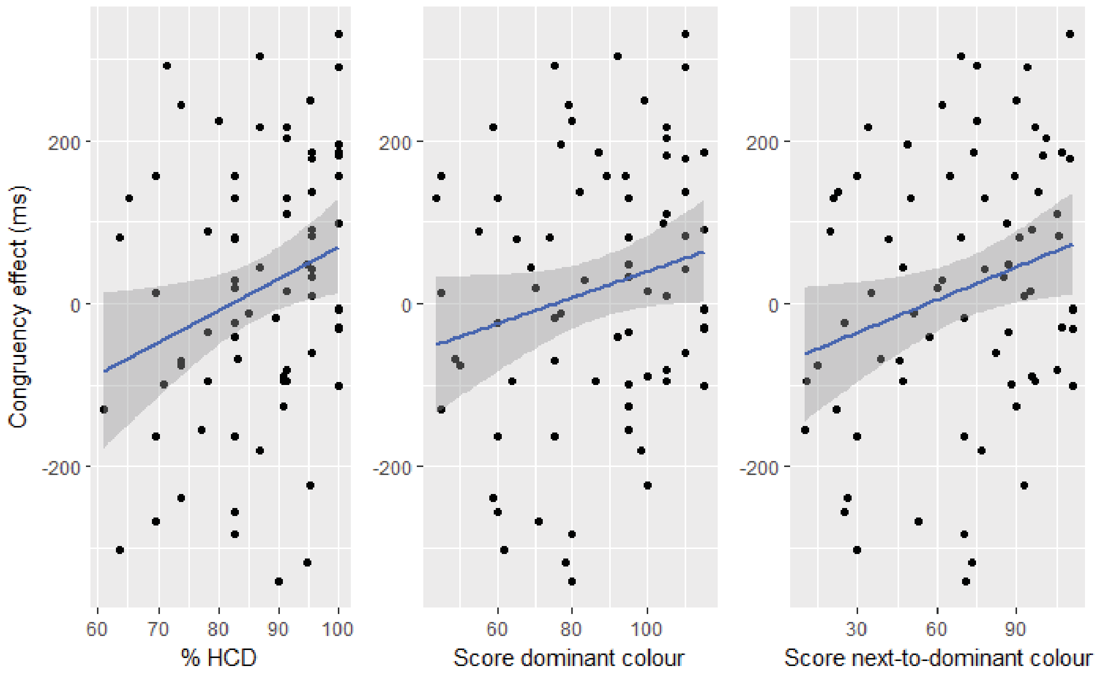

Figure 8-3. Correlations between size of congruency effect in ms and colour-diagnosticity of high colour-diagnostic (HCD) item as measured by a) percentage of subjects rating item as HCD (left column), b) score of the dominant colour (middle), and c) score of the next-to-dominant colour (right) in Experiment 3.

8.2.4 Experiment 4: Dutch PWI, SOA 0ms (EEG study)

Analysis of Experiment 4 showed a significant correlation between congruency effect size and colour-diagnosticity measured as percentage of positive HCD judgments ($r = 0.283$, $p = 0.007$). Congruency effect size and colour-diagnosticity score of the dominant colour were also positively correlated ($r = 0.308$, $p = 0.004$), as were congruency effect size and colour-diagnosticity score of the dominant minus the second-to-dominant colour ($r = 0.193$, $p = 0.049$).

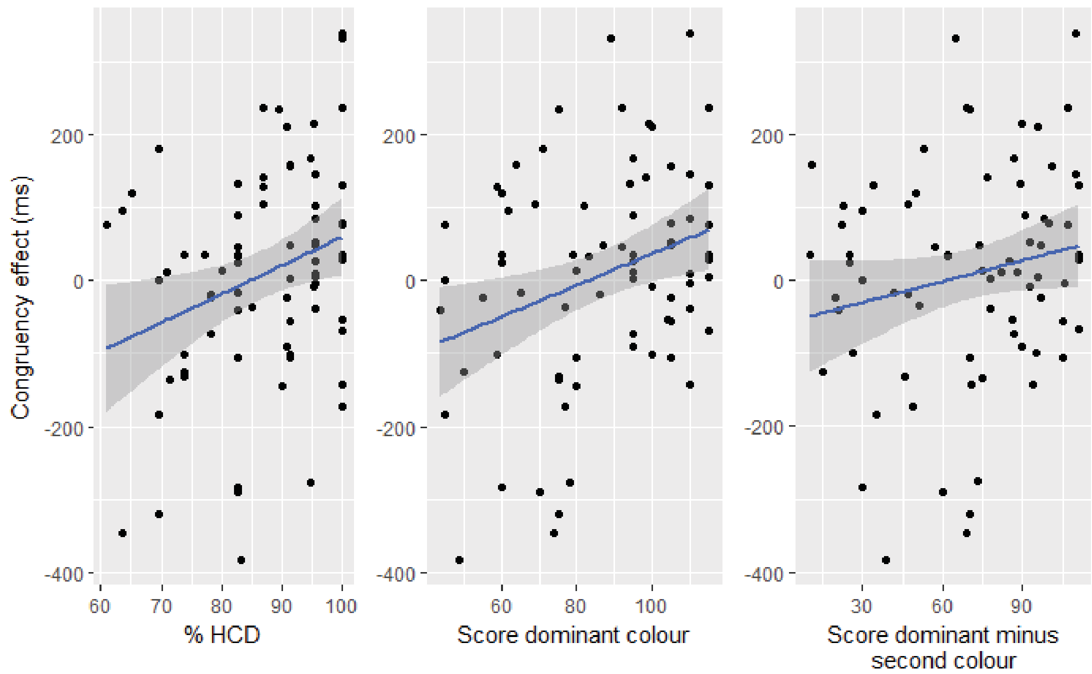

Figure 8-4. Correlations between size of congruency effect in ms and colour-diagnosticity of high colour-diagnostic (HCD) item as measured by a) percentage of subjects rating item as HCD (left column), b) score of the dominant colour (middle), and c) score of the next-to-dominant colour (right) in Experiment 4.

8.3 Discussion

To explore the lack of a significant behavioural congruency effect in Experiments 3 and 4, we conducted correlation analyses between the size of the congruency effect and the degree of colour-diagnosticity for each item. As indices for the degree of colour-diagnosticity, we employed three measures based on a pre-study. Our results showed that the size of the congruency effect depended linearly on degree of colour-diagnosticity when correlated with all three colour-diagnosticity measures in Experiments 3 and 4, where we did not find a significant congruency effect and the overall congruency effect size was smaller. In Experiments 1 and 2, where we found significant congruency effects at SOA -400, -200 and 0, the analysis did not yield a significant correlation between the size of this congruency effect and colour-diagnosticity.[17] The results from these correlation analyses provide evidence for a congruency effect in Experiments 3 and 4, which was graded by the degree of colour-diagnosticity of the chosen items: Items that exhibit a higher degree of colour-diagnosticity showed a larger congruency effect.

However, following this interpretation, we should also expect a significant correlation of degree of colour-diagnosticity and congruency effect size in Experiments 1 and 2 (which was not the case). Experiment 1 shared the same stimulus set as Experiments 3 and 4, where significant correlations were present. Therefore, the discrepancies cannot be fully based on the choice of stimulus set. It is conceivable that the manipulation of SOA is responsible for the lack of a correlation between degree of colour-diagnosticity and the size of the congruency effect in Experiment 1: In this experiment, the colour distractor was presented 400ms before the target picture, that is, at a longer negative SOA than in Experiments 2, 3 and 4. When the colour attribute is pre-activated at a long negative SOA such as -400ms, the typical colour of the target item may have been activated more strongly by the time processing of the target picture begins. In this way, the already strongly activated attribute might boost activation levels of the target concept enough to produce a congruency effect, even for those items that did not show a congruency effect in Experiments 3 and 4. In these experiments, we presented the distractor word simultaneously with the picture, so it is possible that activation of the distractor would not be strong enough to produce a congruency effect for all items. The lack of a significant correlation between the degree of colour-diagnosticity and the size of the congruency effect in Experiment 2 is difficult to explain theoretically and could be attributable to

[17] The correlation between the congruency effect size and colour diagnosticity measures as percentage of subjects rating the item as high colour-diagnostic at SOA +200ms reached significance. However, since this effect was not robust (nonsignificant for the other two colour-diagnosticity measures), we do not consider it for further discussion.

larger random variation at the lower end of the colour-diagnosticity scale. Importantly, also in Experiment 2, highly colour-diagnostic objects exhibited a congruency effect.

In summary, the additional correlation analyses indicate that there was in fact a congruency effect present in Experiments 3 and 4, but that it was limited to very highly colour-diagnostic objects. In this way, the additional analyses resolved the apparent discrepancy in findings between Experiments 2, 3 and 4 in terms of the congruency effect, and provided evidence that throughout all experiments in the present dissertation, a typical colour distractor facilitated naming HCD objects compared to an atypical colour distractor.

9 General discussion

The present dissertation aimed to investigate how the activation of attributes within a frame, in this case, the colour attribute, affects naming the object modelled by the frame. To this end, we conducted four experiments using the PWI paradigm, two of which (Experiments 1 and 4) featured the measurement of EEG signal in addition to reaction times and accuracy rates to achieve a more fine-grained insight into the time-course of naming.

Results from Experiment 1 showed that when presented at a long negative SOA (-400ms), typical colour distractors help naming HCD objects as reflected in shorter reaction times compared to atypical colour distractors. This congruency effect was not reflected in the P2 component. Furthermore, analysis of Experiment 1, in particular the effects of colour-diagnosticity and repetition priming, cast doubts on the interpretation of the P2 component as an index of difficulty. Our results rather strengthen accounts found in the literature that interpret the P2 component as reflecting perceptual or conceptual rather than lexical processes.

Experiment 2 investigated the time course of this congruency effect in a further reaction time experiment using the picture-word interference paradigm with three different SOAs (-200, 0, and +200ms). The results showed that when the distractor precedes the target picture or is presented at the same time, there is a congruency effect showing facilitation by typical colours compared to atypical colours for HCD objects, but not for low colour-diagnostic objects. These findings speak for a perceptual/conceptual or lexical locus of the congruency effect, while ruling out a locus at a processing stage later than lemma access. Since German stimuli were used instead of Dutch stimuli as in Experiment 1, the results also speak for cross-linguistic persistence of the congruency effect.

Experiments 3 and 4 were identical except for the additional measurement of EEG data in Experiment 4. In both experiments, we presented the distractor word at SOA 0ms. The congruency effect found in Experiments 2 did not reach significance. However, further correlational analyses revealed that this difference could be due to the choice of stimulus set, as the size of the congruency effect depended on the degree of colour-diagnosticity of the experimental stimuli in the item set: In Experiments 3 and 4, the congruency effect was present for highly colour-diagnostic objects only. As in Experiment 1, the congruency effect was not reflected in modulations of the P2 component. Instead, the effects of colour-diagnosticity and repetition priming suggest that other cognitive processes besides lexical access might differentially affect the P2 component, complicating its interpretation as an index of lexical access.

9.1 Theoretical implications

The following paragraphs will discuss theoretical consequences for a) theories on the locus of facilitatory semantic effects in the PWI paradigm, and b) frame-theoretical models of conceptual representations.

9.1.1 The locus of the congruency effect

One of the central questions in this thesis is whether pre-activation of typical colours influences lexical access. The results showed found that pre-activation of typical colours resulted in a congruency effect, facilitating naming responses. However, the effect was not reflected in modulations of ERP components, allowing no direct inference as to which processing stage in naming the picture was affected by the colour distractor. Therefore, at this point, conclusions as to which processing stage could be affected by the congruency effect found in Experiment 1 have to be based on previous proposals in the literature, which will be outlined in the following.

There is an ongoing debate in terms of the lexical locus of interference effect in PWI; some authors attribute these effect to the lexical level (e.g., Piai et al., 2012), others have situated them at earlier, prelexical stages of processing (e.g., Dell'Acqua et al., 2007; van Maanen et al., 2009). With respect to facilitatory effects, like the congruency effect in the present dissertation, 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, Melinger, & Abdel Rahman, 2011). Even though the congruency effect in the present thesis was not present in the ERPs and can therefore not directly be compared to their results, 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 120-220ms time window. According to Piai et al. (2012), picture-shape processing takes place in a similar time frame (at ca. 100-200ms). 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, Reis 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 block, they observed interference from associates, which they attribute to the activation of a lexical cohort, which would not be activated by associatively related distractors in the semantically heterogeneous blocks. They found a modulation of the ERP components as a function of both associative and semantic relatedness bilaterally in the time window between 200 and 300ms. 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 et al., 1999). This is compatible with our findings that the congruency effect was present when the distractor was presented before the picture (at -400ms and -200ms), or when it was presented at the same time.

The lack of ERP effects of congruency might reflect differences between the present study and previous studies investigating semantic facilitation in PWI: Hirschfeld et al. (2008) used nouns as distractors (e.g., *fur* - CAT) and compared them with unrelated words (e.g., *flower* - CAT). In our case, we used adjectives to refer to values of specific attributes of the concept in all conditions (typical and atypical colour adjectives such as *red*, values of unrelated attributes such as *fast* for BANANA). Arguably, adjectives are less likely to be perceived as possible responses than basic-level nouns, and would therefore not compete with the target object's name for lexical access. Similarly, Aristei et al. (2011) used semantically associated pictures referred to with nouns. These factors limit direct comparability of Experiment 1 to these previous studies. It is also possible that the congruency effect observed in the reaction times was too subtle to induce significant modulations of the ERPs. However, our behavioural evidence from Experiments 1 to 4 provides support for both a pre-lexical and lexical locus of the congruency effect. They rule out the possibility that the effect only starts with lexical processing, or even later than that.

9.1.2 Consequences for frame-theory

In regard to frame theory, we can revise our previous suggestion (Redmann et al., 2014) that frames should behave as in non-decompositional accounts of conceptual representation, meaning that conceptual attributes do not have direct access to the lexicon. In the present study, when priming the typical colour via a colour word, we found a facilitatory congruency effect at SOA-400ms, SOA -200ms and SOA 0ms. This finding suggests that pre-activation of the typical colour was effective during conceptual and lexical processing stages. The findings rule out that the effect only starts with lexical processing, or is only effective in processing stages later than lexical access. Furthermore, we found no inhibitory effect of colour priming. This finding makes it less likely that the colour had to activate the central node of the target's concept before activating the lexical entry, since this would have been the case for all other concepts sharing the attribute-value combination. If all of these central nodes would have been activated, and would have consequently activated their lexical entries, we would have expected to find inhibition, which we did not. This suggests that the distractor exerts its influence not only on the conceptual level, but also directly on the lemma level.

Our findings are compatible with decompositional accounts of lexical access to conceptual representations: (Pre-)activation of the colour attribute via its name resulted in facilitated access to the target word. Decompositional accounts assume that lexical entries are accessed on the basis of collections of conceptual features such as *red*(x), so they would predict this facilitatory influence of pre-activating the colour attribute on naming. Our finding suggests that when modelling conceptual frames and their connections to lexical entries, it is feasible to assume links not only between the central node of a frame, but also between characteristic values of its attributes (such as "red" in the case of "tomato", see Figure 2-1).

There have also been proposals on how to explain facilitatory effects on naming caused by pre-activation of conceptual components using non-decompositional accounts. In these frameworks, conceptual components (in the form of associatively linked conceptual nodes) do not have direct access to the lemma, thus, facilitation would not straightforwardly be predicted by these models. However, there have been attempts to explain how facilitation from associates can be explained also within a non-decompositional framework. One line of accounts is based on a trade-off between conceptual facilitation and lexical competition (e.g., Abdel Rahman & Melinger, 2009). Following this account, associates and conceptual components always prime the target at the conceptual level. When a cohort of sufficient strength and size causes enough competition at the lexical level (such as the one activated by category coordinate distractors), the net reaction time effect is inhibition, otherwise it is facilitation.

In conclusion, our results suggest that it would be most parsimonious to model frames in a decompositional manner, with direct connections not only between conceptual properties and the central node of the frame, but also between conceptual properties and the lemma corresponding to the concept. According to Petersen (2007, p. 4), frame structures should be "as simple and rigid as possible", and it should be avoided to include "elements […] for merely technical or computational reasons", which suggests that given the present results, the simpler model should be chosen. Future research is needed to allow a stricter verdict as to whether these direct connections between conceptual features and the lemma are not only the simpler, but possibly the only reasonable assumption.

Our findings of a colour congruency effect have further 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. Ongoing work on probabilities and modelling of prototypes in frames (Schurz, 2012) should be combined with further empirical studies to shed light on these questions.

9.2 Methodological implications

Results from Experiments 1 and 4 cast doubts on the interpretation of the P2 component as an index of lexical access (e.g., Costa et al., 2009; Strijkers et al., 2010; Strijkers et al., 2011). Both ERP studies in the present dissertation showed repetition priming and colour-diagnosticity effects that affected the P2 in a similar way, but had different effects on reaction times. The more positive P2 component found for repeated items is problematic for an interpretation of the P2 component as a reflection of difficulty of lexical access. It seems more likely that the occipito-parietal P2 component is modulated by several underlying cognitive processes, which overlap in timing or occur simultaneously. These processes may involve perception and object identification, and possibly attention, besides lexical access. Further research is needed to investigate if and how these different underlying components can be teased apart. To this aim, it could be useful to compare different tasks in one study, where one task involves lexical access (such as naming), whereas another task involves a vocal response to ensure comparability, but no lexical access (such as answering "yes" or "no" in a categorisation task), taking into account possible confounds and working with stimuli that are closely matched on other dimensions to allow precise conclusions.

10 Conclusion

The present dissertation investigated the (pre-)activation of conceptual components in language production by means of a series of behavioural and electrophysiological studies. The results confirm the finding that object naming latencies are influenced by object category: HCD objects, which tend to be natural objects, were named more slowly than LCD objects throughout all experiments. The colour-diagnosticity effect was also reflected in a larger amplitude of the occipito-parietal P2 component, mainly over the right hemisphere. Furthermore, the results provide evidence for a behavioural facilitation effect of (pre-)activating typical colours in a PWI paradigm. This congruency effect was found only in the case of HCD objects, supporting Tanaka and Presnell (1999)'s colour-diagnosticity hypothesis. These results suggest that conceptual frame structures should incorporate direct connections between conceptual attributes such as typical colours and the lemma corresponding to the object denoted by the frame. From a methodological point of view, the repetition priming effect found in Experiments 1 and 4 casts doubt on the interpretation of the P2 component as an index of lexical access, but rather suggests that multiple underlying processes modulate this component collectively.

11 References

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Appendix

Items and distractors used in Experiments 1, 3 and 4

List of high and low colour-diagnostic experimental items in Experiments 1, 3 and 4 (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 Experiments 1, 3 and 4 (*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)

Items and distractors used in Experiment 2

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

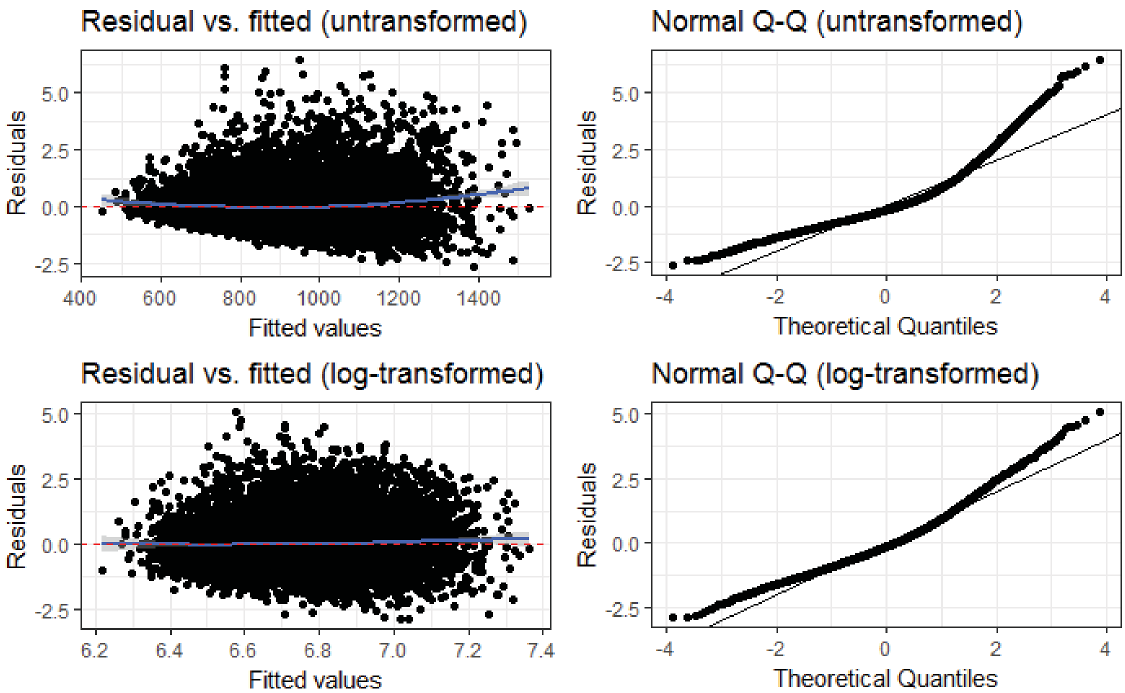
High colour-diagnostic objects	Amboss (anvil), Ameise (ant), Ananas (pineapple), Anker (anchor), Ast (branch), Badewanne (bathtub), Banane (banana), Biene (bee), Birne (pear), Bombe (bomb), Braut (bride), Delphin (dolphin), Ei (egg), Eichel (acorn), Elch (moose), Erdbeere (strawberry), Erdnuss (peanut), 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)

Log transformation of reaction time data

Exemplary diagnostic plots for one of the linear mixed models used in the analysis of reaction times in Experiment 2, comparing reaction time data and log-transformed reaction times.



Experiment 1: Electrophysiological results at frontal and midline electrodes

80-160ms (P1/N1 time-windows)

Frontal

The analysis did not yield any significant main effects or interaction at frontal electrodes in this time-window.

Midline

There were no significant main effects of Colour-Diagnosticity, Distractor Type or Block in this time-window. However, as in the omnibus analysis, the analysis yielded an interaction between Block and Laterality ($F(4,116) = 3.392$, $p = .012$, $pes = 0.105$). Additional separate ANOVAs at the levels of Laterality showed only a marginally significant effect of Block at central electrodes ($F(1.633, 47.348) = 3.291$, $p = 0.055$, $pes = 0.102$), and Bonferroni-corrected post-hoc comparisons between block did not become significant (Table 10.1). There was no significant effect of Block at left ($F(2,58) = 1.984$, $p = 0.147$, $pes = 0.064$) or right electrode sites ($F(1.433, 41.570) = 0.746$, $p = 0.479$, $pes = 0.025$).

160-240ms (P2 time-window)

Frontal

At frontal electrode sites, there was a significant main of Block ($F(2,28) = 14.100$, $p < 0.001$, $pes = 0.327$), as well as an interaction between Block and Laterality ($F(4,116) = 7.694$, $p < 0.001$, $pes = 0.210$). Separate ANOVAs at all levels of Laterality yielded significant main effects of Block at frontal central ($F(2,58) = 16.718$, $p < 0.001$, $pes = 0.366$), frontal left ($F(2,58) = 9.426$, $p < 0.001$, $pes = 0.245$), and frontal right electrode sites ($F(2,58) = 14.122$, $p < 0.001$, $pes = 0.327$). Post-hoc comparisons showed significant differences between the first and second, but not between the second and third Block at all levels of Laterality (see Table 10.1 for mean values and pairwise comparisons).

Midline

At midline electrode sites, there was a significant main effect of Block ($F(2,58)= 23.845$, $p < 0.001$, *pes* = 0.451), as well as an interaction between Block and Laterality ($F(4,116)= 6.605$, $p < 0.001$, *pes* = 0.186). Independent ANOVAs at the different levels of Laterality showed significant main effects of Block on midline central ($F(2,58)= 23.197$, $p < 0.001$, *pes* = 0.444), midline left ($F(2,58))= 18.327$, $p < 0.001$, *pes* = 0.387), and midline right electrodes ($F(2,58)= 20.957$, $p < 0.001$, *pes* = 0.419). Further post-hoc comparisons revealed that at midline central, left and right electrode sites, the second block was significantly more positive than the first block, whereas the difference between the third and the second block was not significant (Table 10.1).

240-340ms (*N300 time-window)*

Frontal

At frontal electrodes, we observed a significant main effect of Colour-Diagnosticity ($F(1,29)= 7.035$, $p = 0.013$, *pes* = 0.195). Like at midline and posterior electrodes, high colour-diagnostic objects showed a larger deflection than low colour-diagnostic objects, but at frontal electrodes, the polarity was reversed, that is, high colour-diagnostic objects ($M = 4.583$, $SE = 1.005$) showed a larger negative peak than low colour-diagnostic objects ($M = 3.944$, $SE = 0.993$).

There was no main effect of Block, but an interaction of Block and Laterality ($F(2.647, 76.762)= 5.369$, $p = 0.003$, *pes* = 0.156). Separate ANOVAs at the levels of Laterality showed that the effect was significant at frontal central electrode sites ($F(2,58)= 3.938$, $p = 0.025$, *pes* = 0.120). Again, the second block was more positive than the first block as revealed in post-hoc tests (Table 10.1), whereas the difference between the second and third block was not significant. There was no significant effect of Block on frontal left electrodes ($F(2,58)= 1.424$, $p = 0.249$, *pes* = 0.047), or at frontal right electrodes ($F(1.590, 46.114)= 2.018$, $p = 0.142$, *pes* = 0.065).

Midline

There was a highly significant main effect of Colour-Diagnosticity in this time-window ($F(1,29)= 18.797$, $p < 0.001$, *pes* = 0.393), as well as an interaction between Colour-Diagnosticity and Laterality ($F(2,58)= 5.939$, $p = 0.005$, *pes* = 0.170). Separate ANOVAs at all levels of Laterality showed a significant main effect of Colour-Diagnosticity at midline central electrodes ($F(1,29)= 13.937$, $p = 0.001$, *pes* = 0.325), where high colour-diagnostic objects ($M = 6.014$, $SE = 0.909$) showed a more positive deflection than low colour-diagnostic objects ($M = 5.125$, $SE = 0.998$). A slightly smaller effect of Colour-Diagnosticity was present at left electrodes, with high colour-diagnostic objects ($M = 4.857$, $SE = 0.618$) showing a larger positivity than low colour-diagnostic objects ($M = 4.401$, $SE = 0.664$; $F(1,29)= 5.388$, $p = 0.028$, *pes* = 0.157). At midline right electrodes, the effect was highly significant, high colour-diagnostic objects ($M = 4.773$, $SE = 0.686$) again showing more positive waveforms than low colour-diagnostic objects ($M = 3.761$, $SE = 0.720$; $F(1,29)= 32.077$, $p < 0.001$, *pes* = 0.525).

We also found a main effect of Block ($F(1.482, 42.980)= 10.571$, $p = 0.001$, *pes* = 0.267). Again, post-hoc comparisons showed that the second block was more positive than the first block, whereas there was no significant difference between the second and third block (Table 10.1).

340-400ms (*P3 time-window)*

Frontal

At frontal electrodes, there was no main effect of Block or any interaction between Block and other factors. There was also no main effect of Colour-Diagnosticity, but the interaction between Colour-Diagnosticity and Laterality was significant ($F(2,58)= 6.304$, $p = 0.003$, *pes* = 0.179). Independent ANOVAs at all levels of Laterality showed a trend for an effect of Colour-Diagnosticity at frontal central electrodes ($F(1,29)= 3.103$, $p = .089$, *pes* = 0.097). High colour-diagnostic objects tended to be more negative than low colour-diagnostic objects. The same trend was visible across frontal left electrodes ($F(1,29)= 2.905$, $p = .099$, *pes* = 0.091), where high colour-diagnostic objects tended to show a larger negative deflection than low colour-diagnostic objects.

As was the case at midline electrodes, a three-way interaction between Colour-Diagnosticity, Block and Laterality became significant ($F(4,116)= 3.064$, $p = 0.019$, *pes* = 0.096), but was not confirmed in separate ANOVAs at the levels of Laterality, where no significant interaction between Colour-Diagnosticity and Block was found (all $p > 0.1$).

Midline

Even though there was no main effect of Colour-Diagnosticity at midline electrode sites, the interaction between Colour-Diagnosticity and Laterality ($F(2,58)= 8.160$, $p = 0.001$, *pes* = 0.220) was significant. Independent ANOVAs at all levels of Laterality revealed that there was no significant Colour-Diagnosticity effect at midline central electrodes ($F(1,29)= 0.059$, $p = 0.810$, *pes* = 0.002) or at midline left electrode sites ($F(1,29)= 1.035$, $p = 0.317$, *pes* = 0.034). However, the effect was present at midline right electrode sites ($F(1,29)= 13.506$), $p = 0.001$, *pes* = 0.318, where waveforms elicited by high colour-diagnostic objects were more positive than those elicited by low colour-diagnostic objects.

There was also a three-way interaction between Colour-Diagnosticity, Block and Laterality ($F(4,116)= 3.156$, $p = 0.017$, *pes* = 0.098). However, separate ANOVAs at all levels of Laterality did not confirm the presence of this interaction (all $p > 0.1$)

Table 10.1. Mean amplitudes in mV (standard error) for block 1, 2 and 3 over left, central and right electrodes and p-values for Bonferroni-corrected pairwise comparisons between the 1st and 2nd, and between the 2nd and 3rd block at frontal and midline electrode sites.

			Block 1	Block 2	Block 3	1 vs. 2	2 vs. 3
80-160ms	Midline	Central	-2.680 (0.811)	-2.368 (0.743)	-1.662 (0.613)	p = 0.986	p = 0.272
		Left	-1.305 (0.613)	-1.035 (0.564)	-0.659 (0.435)	p = 1.000	p = 0.637
		Right	-1.180 (0.517)	-1.132 (0.469)	-0.895 (0.426)	p = 1.000	p = 1.000
	Frontal	Central	-3.139 (0.861)	-2.932 (0.799)	-2.562 (-0.636)	p = 1.000	p = 1.000
		Left	-2.623 (0.755)	-2.247 (0.716)	-2.175 (0.557)	p = 0.230	p = 1.000
		Right	-2.528 (0.736)	-2.157 (0.689)	-2.114 (0.585)	p = 0.269	p = 1.000
160-240ms	Midline	Central	4.762 (0.700)	7.120 (0.813)	7.695 (0.722)	p < 0.001***	p = 0.398
		Left	3.440 (0.568)	5.125 (0.621)	5.347 (0.570)	p < 0.001***	p = 1.000
		Right	3.169 (0.474)	4.815 (0.550)	4.955 (0.529)	p < 0.001***	p = 1.000
	Frontal	Central	3.599 (0.743)	5.742 (0.812)	5.930 (0.674)	p < 0.001***	p = 1.000
		Left	3.577 (0.654)	5.168 (0.746)	4.945 (0.634)	p < 0.001***	p = 1.000
		Right	3.145 (0.653)	4.949 (0.735)	4.776 (0.623)	p < 0.001***	p = 1.000
240-340ms	Midline	Central	4.243 (1.016)	6.355 (1.050)	6.110 (0.916)	p = 0.001**	p = 1.000
		Left	3.599 (0.678)	5.265 (0.691)	5.021 (0.642)	p = 0.001**	p = 1.000
		Right	3.422 (0.726)	4.834 (0.766)	4.544 (0.699)	p = 0.003**	p = 0.869
	Frontal	Central	2.989 (0.539)	4.487 (1.239)	4.206 (0.983)	P = 0.037*	p = 1.000
		Left	4.300 (0.975)	5.079 (1.069)	4.552 (0.867)	p = 0.310	p = 0.598
		Right	3.817 (1.037)	4.751 (1.125)	4.190 (0.940)	p = 0.121	p = 0.437
340-400ms	Midline	Central	3.932 (1.178)	5.937 (1.307)	5.479 (1.164)	p = 0.005**	p = 0.939
		Left	3.034 (0.771)	4.528 (0.866)	4.203 (0.833)	p = 0.005**	p = 1.000
		Right	3.151 (0.826)	4.383 (0.921)	3.900 (0.845)	p = 0.021*	p = 0.586
	Frontal	Central	2.062 (1.389)	2.786 (1.548)	2.010 (1.255)	p = 0.938	p = 0.363

	Left	2.784 (1.116)	2.914 (1.305)	2.095 (1.086)	p = 1.000	p = 0.355
	Right	2.629 (1.200)	2.959 (1.322)	2.048 (1.125)	p = 0.563	p = 0.135

Experiment 4: Electrophysiological results at frontal and midline electrodes

110-200ms (N1)

Frontal

At frontal electrodes, the same overall pattern was present: There was a main effect of Block (F(2,58)= 10.403, $p < 0.001$, *pes* = 0.264), and an interaction of Block with Laterality (F(2,58)= 4.655, $p = 0.002$, *pes* = 0.138). At frontal, central electrode sites, there was a main effect of Block (F(2,58)= 12.258, $p < 0.001$, *pes* = 0.297): The second block (M = 2.410, SE = 0.742) was significantly more positive than the first block (M = 1.334, SE = 0.749; $p = 0.009$, SE = 0.330), but the second and third block (2.910, SE = 0.611) did not differ significantly ($p = 0.182$, SE = 0.257). At frontal, left electrode sites, there was a main effect of Block (F(2,58)= 8.401, $p = 0.001$, *pes* = 0.225). Post-hoc pairwise comparisons revealed that the only significant difference was present between the third (M = 1.989, SE = 0.501) and the first block (M = 0.840, SE = 0.578, $p = 0.005$, SE = 0.332). All other comparisons were nonsignificant (p >0.05). Also at frontal, right electrodes, the effect of Block was significant (F(2, 58)= 8.852, $p < 0.001$, *pes* = 0.324). There was a significant difference between the first (M = 0.835, SE = 0.631) and second block (M = 1.649, SE = 0.605; $p = 0.019$, SE = 0.277), and the first and the third block (M = 1.984, SE = 0.530, p = 0.005, SE = 0.328), but not between the second and third block ($p = 0.462$, SE = 0.229). There were no other significant effects at frontal electrodes.

Midline

At midline electrodes, the repeated-measures ANVOA yielded a highly significant main effect of Block ($F(2,58)= 22.018$, $p < 0.001$, *pes* = 0.432). Block interacted with Laterality ($F(4,116)= 6.123$, $p < 0.001$, *pes* = 0.174). Further independent ANOVAs showed significant effects of Block at central ($F(2,58)= 19.537$, $p < 0.001$, *pes* = 0.403), left ($F(2,58)= 23.584$, $p < 0.001$, *pes* = 0.449) and right electrode sites ($F(2,58)= 15.508$, $p < 0.001$, *pes* = 0.348). At central electrodes, the second block ($M = 4.353$, $SE = 0.699$) was more positive than the first block ($M = 2.901$, $SE = 0.651$; $p = 0.001$, $SE = 0.366$), but the third block ($M = 4.983$, $SE =.616$) did not differ significantly from the second block ($p = 0.121$, $SE = 0.294$). At left electrode sites, the third block ($M = 2.968$, $SE = 0.396$) was more positive than the second block ($M = 2.387$, $SE = 0.442$; $p = 0.018$, $SE = 0.196$), and the second block was more positive than the first block ($M = 1.402$, $SE = 0.372$; $p = 0.001$, $SE = 0.235$). At right electrode sites, the second block ($M = 2.099$, $SE = 0.468$) was more positive than the first block ($M = 1.285$, $SE = 0.443$; $p = 0.004$), but the third block ($M = 2.510$, $SE = 0.406$) did not significantly differ from the second block ($p = 0.165$, $SE = 0.206$). No other main effects or interactions were significant at midline electrode sites in this time-window.

200-320ms (*P2)*

Frontal

There were no significant main effects at frontal electrodes in this time-window. Block interacted with Laterality ($F(4,116)= 2.911$, $p = 0.025$, *pes* = 0.091). Separate analyses at all levels of Laterality showed an effect of Block at frontal central electrodes reached significance ($F(2,58)= 3.215$, $p = 0.047$, *pes* = 0.100), but all post-hoc comparisons between blocks at these sites were nonsignificant (all $p > 0.1$). At frontal left electrodes, the effect of Block was not significant ($F(1.574,45.645)= 3.385$, $p = 0.053$, *pes* = 0.105). This was also the case at frontal right electrodes ($F(2,58)= 1.192$, $p = 0.311$, *pes* = 0.039).

There was an interaction between Distractor Type and Laterality ($F(4,116)= 3.370$, $p = 0.012$, *pes* = 0.104). Independent ANOVAs showed no effect of Distractor Type at frontal central electrodes ($F(1,29)= 0.398$, $p = 0.673$, *pes* = 0.014), at frontal left electrodes ($F(1,29)= 0.095$, $p = 0.909$, *pes* = 0.003), or at frontal right electrodes ($F(2,29)= 1.721$, $p = 0.188$, *pes* = 0.056). No other effects were significant at frontal electrodes in this time-window.

Midline

At midline electrodes, the analysis yielded a main effect of Colour-Diagnosticity ($F(1,29)= 4.619$, $p = 0.040$, *pes* = 0.137); HCD objects (*M* = 1.865, *SE* = 0.499) elicited more positive waveforms than LCD objects (*M* = 1.468, *SE* = 0.490). Colour-Diagnosticity interacted with Laterality ($F(2,58)= 3.930$, $p = 0.025$, *pes* = 0.119). Separate independent ANOVAs at all levels of Laterality showed that there was no effect of Colour-Diagnosticity at midline central electrodes ($F(1,29)= 2.544$, $p = 0.122$, *pes* = 0.081), or at midline left electrodes ($F(2,29)= 0.783$, $p = 0.384$, *pes* = 0.026). However, there was a highly significant main effect of Colour-Diagnosticity at right electrode sites ($F(2,29)= 16.145$, $p < 0.001$, *pes* = 0.358). Waveforms elicited by HCD objects (*M* = 1.872, 0.486) showed a larger positivity than waveforms elicited by LCD objects (*M* = 1.253, *SE* = 0.456).

Again, there was a main effect of Block ($F(2,58)= 9.929$, $p < 0.001$, *pes* = 0.255) and an interaction between Block and Laterality ($F(4,116)= 5.474$, $p < 0.001$, *pes* = 0.159). Separate ANOVAs showed a significant effect of Block at midline central ($F(2,58)= 7.491$, $p = 0.001$, *pes* = 0.205), midline left ($F(2,58)= 15.966$, $p < 0.001$, *pes* = 0.355) and midline right electrode sites ($F(2,58)= 4.425$, $p = 0.016$, *pes* = 0.132). Post-hoc comparisons showed that at midline central electrodes, only the third block (*M* = 3.049, *SE* = 0.769) differed significantly from the first block (*M* = 1.398, *SE* = 0.697; *p* = 0.004, *SE* = 0.469), all other comparisons were nonsignificant (*p* >0.05). At midline left electrode sites, all blocks differed significantly from each other. The second block (*M* = 1.258, *SE* = 0.512) was more positive than the first block (*M* = 0.138, *SE* = 0.389, *p* = 0.018, *SE* = 0.376), and the third block (*M* = 2.103, *p* = 0.501) was more positive than the second block (*p* = 0.010, *SE* = 0.264). At midline right electrodes, only the third (*M* = 2.049, *SE* = 0.485) and first block (*M* = 1.125, *SE* = 0.500) differed significantly (*p* = 0.041, *SE* = 0.351, all other *p* > 0.05). No other main effects or interactions were significant at midline electrode sites in this time-window.

320-450ms (*N300/P3*)

Frontal

There were no significant main effects or interactions at frontal electrodes in this time-window.

Midline

At midline electrodes, there was a significant effect of Block (F(1.675,48.567)= 8.445, *p* = 0.001, *pes* = 0.226), which also interacted with Laterality (F(4,116)= 6.463, *p* < 0.001, *pes* = 0.182). The effect of Block was significant at midline central (F(2,58)= 1.624, *p* = 0.206, *pes* = 0.053), midline left (F(2,58)= 12.563, *p* < 0.001, *pes* = 0.302), and midline right (F(1.633,47.360)= 3.519, *p* = 0.046, *pes* = 0.108) electrode sites. Post-hoc comparisons showed that at midline central electrodes, the first block (*M* = 3.151, *SE* = 0.927) differed significantly from the second block (*M* = 5.291, *SE* = 1.089; *p* = 0.003, *SE* = 0.576) and from the third block (*M* = 5.029, *SE* = 1.034; *p* = 0.030, *SE* = 0.681), whereas there was no difference between the second and third block (*p* = 1.000, *SE* = 0.487). The same pattern emerged at midline left electrodes, where there was a significant difference between the first (M = 1.193, SE = 0.0634) and second block (M = 2.970, SE = 0.779; p = 0.003, SE = 0.536), but not between the second and third block (M = 3.412, SE = 0.682; p = 0.714, SE = 0.367). At midline right electrodes, none of the pairwise comparisons between blocks was significant (all $p > 0.05$). There were no other significant effects in this time-window at midline electrodes.

Versicherung

„Ich erkläre hiermit, dass ich die vorliegende Arbeit selbständig und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt und die aus fremden Quellen direkt oder indirekt übernommenen Gedanken als solche kenntlich gemacht habe und dass die Arbeit bisher in gleicher oder ähnlicher Form keiner Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht wurde. Bereits veröffentliche Teile sind in der Arbeit gekennzeichnet."

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