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Crab or lobster? Mental principles underlying the categorization of crustaceans by biology experts and non-experts

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ABSTRACT

Object categorization is an important research topic not only in the field of biology but also in psychology. So far, however, the mental principles guiding categorization in biology have not been systematically investigated from the viewpoint of psychology. We focused our study on the shape-based categorization processes of decapod crustaceans, incorporating the perspectives of both disciplines in order to shed more light on this phenomenon. Thus, in parallel to the investigation of the principles of morphology-based categorization of decapods, we examined the mental representations of the concepts of crustaceans and the development of these representations in human memory. For this purpose, we created a set of standardized and modularized images of decapod crustaceans consisting of a series of morphed exemplars of crabs and lobsters, which served as a stimulus basis for investigating category judgments. The images were ordered linearly on a continuum changing from a 'crab' to a 'lobster' pole by systematically manipulating certain categorization-relevant features like the shape of the carapace and the angle of the claws. This precisely controlled material allowed us to systematically investigate the influence of qualitative and quantitative changes in specific features of decapods on people's category judgments. Moreover, we also analyzed how different levels of biological expertise and prior knowledge influence the aforementioned processes. We conducted a psychological experiment by using a cognitive performance test with groups of biology students at different stages of expertise as well as naïve non-experts. Our results show that category judgments in the case of crustaceans specifically depend on the morphological, shape-based form information in the presented image but not on the degree of prior knowledge about the to-be-categorized material. Thus, the form information is robust and dominant across different levels of expertise. These current findings allow conclusions about the nature of categorization processes for decapod crustaceans and the impact of perception-guided formation of mental concepts in human memory. This underlines the need to combine methodological and conceptual knowledge from biology and psychology to understand the principles of categorization as a research topic in scientific investigations.

1. Introduction

1.1. The issue of crab classification

Classifying organisms into categories based on shared characteristics is an important issue in biological systematics. Mere typological concepts can result in groupings different from actual phylogenetic units, and this often results in a clash between taxonomic categorizations and monophyletic groups based on phylogenetic analyzes (Yoon, 2009; Scholtz, 2013). This clash is not restricted to intuitive classifications of biological forms by laypersons versus the expertise of specialists but remains a continuous problem in science itself, where homology versus convergence and taxa versus Linnaean categories confuse the matter. A clear example of this problem is the category 'crab' within decapod crustaceans. The typological concept of a crab is based on a set of morphological characteristics including a widened trunk and

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a tail that is folded beneath the trunk, both resulting in a compact body shape. The evolutionary process that leads to the body organization of a crab from a long-tailed (lobster-like) ancestor is referred to as carcinization (Borradaile, 1916; Scholtz, 2014). The phylogenetic entity of crabs, the Brachyura, often called 'true crabs', comprises these crabs by definition. However, not all members of the Brachyura are fully carcinized and do not therefore match the typological concept of a crab (Scholtz, 2014). Additionally, crabs in the typological sense are not only found within the Brachyura, but also in several other decapod crustacean groups that underwent carcinization convergently (see McLaughlin and Lemaitre, 1997; Morrison et al., 2002; Reimann et al., 2011; Tsang et al., 2011; Anker and Paulay, 2013; Bracken-Grissom et al., 2013; Guinot et al., 2013; Keiler et al., 2013). Therefore, in the case of crabs, classification based on phylogenetic relationships strongly contradicts the more intuitive grouping by external morphological similarities (see Scholtz, 2014).

The Brachyura is a very diverse group consisting of around 7000 species, greatly differing from one another in several characteristics such as size, color, body shape, or morphology of chelipeds and legs, to name just a few (see Ng et al., 2008). The general body shape, particularly the trunk of the crabs, which is dorsally armored by the carapace, can vary widely among crabs. A transversely ovate carapace shape as in the edible rock crab (*Cancer pagurus*) or a rectangular to trapezoid shape as in the shore crab (*Carcinus maenas*) correspond to what is considered as "typical" crab, but there are also other carapace shapes present among crabs, such as triangular, circular, and elongated. In contrast to crabs, long-tailed decapod crustaceans such as lobsters (Nephropoidea), crayfish (Astacoidea), and rock lobsters (Achelata) have elongated carapaces and thus a rather similar, overall torpedo-like shape.

In the present study, we address the issue of decapod classification, in particular the distinction between crabs and lobster-like animals along with the role of the different carapace shapes in an interdisciplinary approach focusing on psychological mechanisms.

1.2. Psychological background: mental representations and expertise

It is commonly assumed within psychology that in order to recognize familiar objects and to classify them into category structures, incoming perceptual object information is matched against prototypical representations of respective object classes. Prototypical representations are abstract, ideal objects stored in long-term memory, which represent the average, essence, or central tendency of a class or category (Rosch and Mervis, 1975; Klatzky, 1980, 1986 but see exemplar-based theories for alternative perspectives on representations, Nosofsky, 1988; Nosofsky and Palmeri, 1997). Since humans divide the world into categories (generally designated by names e.g., 'dog' or 'animal'), the concrete objects within each category are considered equivalent (Rosch et al., 1976a).

Mental categories are related to one another by means of class inclusion: the greater the inclusiveness, the higher the level of abstraction (Rosch et al., 1976a). In the mental category structure of concrete objects, three main levels can be distinguished. Categories on the most abstract level are the superordinate categories (e.g., 'furniture', 'vehicle') sharing only a few attributes among each other. Categories one level less abstract are on the basic level of abstraction (e.g., 'chair', 'car') and can be differentiated the most easily from one another, while categories below the basic level are the subordinate categories (e.g., 'kitchen chair', 'sports car') containing many attributes overlapping with similar categories (e.g., with other kinds of chairs). Categories on the basic level are characterized as carrying the most information, possessing the highest cue validity, best mirroring the correlational structure of the environment, are recognized first and thus are the most typical and commonly used in contrast to superordinate and subordinate categories (Rosch et al., 1976a). Within the basic level, members of a category often differ from one another in typicality: based on the experimental evidence of the typicality effect, some members are better examples of the given category in the sense that they are more salient, faster identified, better remembered, and thus, better representatives of the category (Rosch et al., 1976b).

Mental categories are, however, not fixed but rather flexible in the sense that prior information, learning, and expertise can transform them. That is, while earlier psychological theories implicitly claimed that the mental representations of object classes are stable and accurate (e.g., Bruce, 1994), recent studies have shown that the prototypes of complex objects can be strongly influenced by prior visual experience, leading to changes in category representations (see Carbon et al., 2007; Daelli et al., 2010; Webster and MacLeod, 2011; Strobach and Carbon, 2013). Thus, mental categories and object representations are flexible, and the perceptual similarity between objects is not only influenced by their physical properties and category structure, but also by learning histories of the stimuli (Tanaka et al., 2012). As an effect of learning, prior knowledge, and especially specific knowledge or expertise leads to the formation of representations which reflect the objects as a whole rather than representing only their individual features. That is why experts classify objects into their categories through a holistic process in which the overall impression of the object is immediately assigned to the category in one step, while non-experts arrange the objects in their categories through successive examination of individual sub-features (Gauthier et al., 2000). Expertise changes the usage of category structures as well. Academically trained people possess elaborate, fine-grained representations of the objects of their discipline. That is, while the recognition of everyday objects typically occurs first on the basic level of representations and then expands to both the super- and the subordinate levels, expertise shifts the entry point of the process to the subordinate level (Belke et al., 2010). However, experts' holistic representations (Kanwisher, 2000) may be, upon encountering the real objects, more sensitive to their physical properties (e.g., the orientation of objects, see Diamond and Carey, 1986), yet suggest a lower changeability in the presence of different individual exemplars (see Gauthier and Tarr, 2002; Daelli, 2011; Tanaka et al., 2012).

1.3. Problems and aims

Many psychological studies have focused on the categorization of complex objects and the influence of expertise, yet there are still considerable gaps in the literature. The majority of studies has, for instance, examined these questions using human faces (see Kanwisher, 2000; Carbon et al., 2007; Webster and MacLeod, 2011; Strobach and Carbon, 2013). Furthermore, the small number of studies targeting expertise regarding non-face objects has typically investigated completely artificial, fictional, and not real objects (see Gauthier and Tarr, 2002). In addition, and more importantly, in several cases of the few studies using biological and existing objects, the selection criteria for the expert groups was rather problematic: either based on self-evaluation, or not thoroughly reported (see Gauthier et al., 2000).

Nevertheless, the psychological framework of the influence of expertise on object categorization could be easily applied to zoology, since for instance the classification of decapod crustaceans, and especially crabs also has its scientific challenges. Although the approximate ratio of the length and width of the carapace in crabs is close to equal (Scholtz, 2014) and statements about the typicality of certain carapace shapes are widely accepted, so far the investigation of which body part of the animals influences their perception, recognition, and classification most, or how characteristic the various carapace shapes are, is lacking from the literature. In general,

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