Experimental Design for a replication study of ‘Graded motor responses in the time course of categorizing atypical exemplars’ (Dale et al., 2007)

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Background

Knowledge representation is an important aspect of human cognition. In order to generalize knowledge and make it universally understandable, comparable and learnable, we use concepts and categories. A concept is a representation of an entities’ abstract meaning. It provides us with a general idea about its properties such that we can identify whether an instance fits a concept or not. A category is the collection of all instances that fit a certain concept. Investigating how we acquire such conceptual knowledge and use it to guide categorization in our daily lives has been a major topic in research.

One interesting issue that emerged from this field of research is that not all instances have a unique membership, i.e. belong to only one category. Some instances do not match the underlying concept of their category perfectly hence they are not a typical example of their category and share conceptual features with other categories, meaning that multiple categories compete with each other during the categorization process. These instances exhibit more of a fuzzy membership for their category and seem to be harder to categorize, which lead to the question of how exactly we categorize an instance according to our conceptual knowledge, and how we deal with the problem of typicality during categorization. Research trying to answer these questions diverged into diverse directions and consequently gave rise to the development of different theories of categorization (for an overview see Goldstone, Kersten, & Carvalho, 2012: pp. 611-619).

In addition to multiple theoretical approaches, experimental methods developed as well. Initial research focused more on the outcome of categorization than the whole process of it. (Dale, Kehoe, & Spivey, 2007: p.15 f.) Recent studies, however, started to investigate the temporal dynamics of categorization processes and take physical movements (e.g. eye movement, hand movement) as indicators of the underlying cognitive processes into account. This line of research exploits the notion that our movements are continuously guided and updated by underlying cognitive processes. Thus, observing those movements can tell us something about the responsible cognitive processes as well (see Freeman, Dale, & Farmer, 2011 for hand movement studies in particular).

Dale, Kehoe, & Spivey (2007) investigated the temporal dynamics of decision processes in a mouse tracking study. In the first experiment of their study, they looked at the categorization process of animal names with different ratios of typicality relative to their category. They compared atypical exemplars (e.g. penguin) that exhibit competing categories (are penguins mammals *or* birds) with typical exemplars (e.g. dog) that show an unambiguous categorization (mammal).
Just like the authors, we want to gain further insight into the cognitive mechanisms of categorization and how the typicality of an entity for its' category might influence these processes, specifically, the timely succession of the process. We try to reconstruct Dale et al.'s observations and to verify their drawn conclusions by replicating the first experiment (Dale, Kehoe, & Spivey, 2007: pp.16-20) of their study, as well as check whether we get similar results.
Following Dale et al.'s experimental design, we examine the categorization processes of typical vs. atypical animals and the time course of the categorization process by keeping track of the hand, i.e. mouse movement, while participants choose a category for a presented exemplar. The underlying intuition is that the uncertainty in categorizing atypical exemplars due to the competition of categories should be evident in the mouse movement trajectories. For example, when categorizing the animal *penguin*, one's mouse movement might drift to the category *mammal* first, because penguins do not fly like birds usually do, i.e. penguins do not fit the concept of birds perfectly which hampers our categorization process. But after some more contemplation, one will categorize them as *bird* and the mouse will change its path to the right category. Compared to the categorization of *dog*, where we are immediately certain that it belongs to *mammal*, the mouse movement will be quite straight with less divergence.
Thus, the mental uncertainty in categorization should also be visible physically in the staggering hand movements of a participant.

The differences in processing atypical vs. typical exemplars will be tested by means of our hypothesis and with the help of our experimental setup which are introduced in the following.

Hypothesis

These hypotheses closely resemble the original study's hypotheses:

During the categorization of atypical exemplars (experimental trials) the two category options compete more, i.e. stand in greater conflict than during the categorization of typical exemplars (control trials). This is represented by mouse trajectories gravitating more towards the competing category (incorrect category) in experimental trials than in control trials.
This intuitive description is made operationalizable by the following non-directional null-hypothesis:

Time-normalized:

H0: The difference between the typical and atypical condition's x-coordinates is significant ($p<.05$) in less than 8 consecutive time steps (of 101).
H1: The difference between the time-normalized typical and atypical condition's x-coordinates is significant ($p<.05$) in at least 8 consecutive time steps (of 101).

Space-normalized:

H0: There is no significant effect ($p>=.05$) of trial type on the variance of mouse coordinates within 500ms time bins.
H1: There is a significant effect ($p<.05$) of trial type on the variance of mouse coordinates within 500ms time bins.

Design

In this experiment we will implement a within-subject design with two conditions - control and experimental condition - whose order is randomized.

Materials

There are 3 practice trials and 19 target trials. Each trial stages the name of an animal that needs to be categorized and two possible categories to choose from. In the 19 target trials there are 6 atypical animals (experimental trials) and 13 highly typical ones (control trials) - the animals are typical or atypical in regards to a certain category. There are five different categories: mammal, reptile, bird, fish, insect and amphibia. In the experimental trials the atypical animal is more difficult to categorize since both provided categories share conceptual features with the animal.
For the target trials we will use the lexical stimuli provided by Dale, Kehoe, & Spivey (2007):

Table of Atypical/Typical Animals + Categories for Target Trials, Correct Category in *italics*

Atypical exemplars	Typical exemplars
Eel - *fish* or reptile	Hawk - *bird* or reptile
Whale - *mammal* or fish	Dog - *mammal* or insect
Sea lion - *mammal* or fish	Horse - *mammal* or bird

Penguin - *bird* or fish	Shark - *fish* or mammal
Butterfly - *insect* or bird	Alligator - *reptile* or mammal
Bat - *mammal* or bird	Rabbit - *mammal* or reptile
	Chameleon - *reptile* or insect
	Cat - *mammal* or reptile
	Sparrow - *bird* or mammal
	Goldfish - *fish* or amphibian
	Salmon - *fish* or mammal
	Rattlesnake - *reptile* or amphibian
	Lion - *mammal* or fish

Since there were no stimuli given for the practice trials, we report newly created ones:

Table of Atypical/Typical Animals + Categories for Practice Trials, Correct Category in *italics*

Atypical	Typical
Frog - *amphibian* or reptile	Turtle - *reptile* or fish
	Ant - *insect* or reptile

Procedure

We try to follow the experimental design of the original study as closely as possible. As a main difference, we report that our study will be an online study as compared to a laboratory study. Since we cannot offer a laboratory setting, we provide participants with a web link via email. When participants follow the link, a website that hosts the experiment is opened. General information about the experiment, instructions and guidelines are all given in written form such that participants know what to do without an experimenter telling them. After the participants read through the instructions, the experiments proceeds on the website similar to how it would happen in a laboratory. Since we cannot influence the actual setting of the participants' environment, participants have to answer relevant questions after the experimental part which corresponds to our extended exclusion criteria (more on that below). With those questions and criteria we try to adapt the online experiment to the standard of the original study and diminish possible differences.

The experiment is divided into four parts:
(i) introduction & instructions
(ii) practice phase
(iii) main test phase
(iv) post-experiment questionnaire

First, participants are welcomed to the online experiment and are asked to do the experiment on a computer instead of a laptop or similar, if possible. With this, we try to prevent participants from using phones, tablets, etc. because those devices often cannot report the kind of continuous mouse movements that we want to analyse and the movement itself might be quite different when using a touchpad or touch screen in comparison with a mouse. Furthermore, we state that the experiment is in english and ask participants to not stop the experiment if they struggle with the language but to continue and report those problems at the end of the experiment. In the original study all participants were students of an american university, such that an adequate level of english skills could be expected by the researchers. Our study, however, will be distributed in an international student community and their social environments, hence we cannot confidently conclude that individual english skills are sufficient and all english words are comprehended. With this statement we want to prepare participants for the task and avoid indecisiveness during the experiment due to language problems.
After that, the descriptions for the task they are about to perform are shown. It is stressed that participants should be as fast and as accurate as possible in their responses. This is important because reactions should be as intuitive as possible, i.e. fast, without overthinking the task or researching the correct answer if they are uncertain. And yet we do not want participants to sacrifice accuracy for speed, since we are interested in data of correct categorization.
After reading the instructions, participants will complete 3 practice trials to get familiar with the task.
For each trial the two possible categories for the animal name are randomly assigned to one of the upper corners of the screen. Participants will see the category names in their assigned positions for 2000 msec. After that a text field labeled ‘Click Here’ will appear at the bottom center which will elicit the appearance of the animal name as soon as participants click it. When the animal name is shown in the bottom center of the screen, participants have to decide which category it belongs to and select the appropriate one with a mouse click in the corresponding corner. Once a choice was made, a new trial starts.
Each trial has a time limit of 5.0 seconds to filter out all responses that are not intuitive. We decided on 5.0 seconds based on our impressions after testing the experiment thoroughly ourselves. Shorter durations seemed to insufficient time for categorization, especially in cases of atypical exemplars. However, more than 5 seconds seemed to raise the risk of participants researching the animal or contemplating to much about their decision.
After practice, 19 target trials follow in the same manner. All stimuli are presented in random order and neither in the practice nor in the main trials the participants are provided feedback about whether their category choice was correct.
Lastly, the participants are asked to provide additional information: they should state

i) whether they used a mouse or the laptop's touchpad during the experiment
ii) which hand they used to move the cursor during the task and
iii) how much on a scale from 0 (understood nothing) to 7 (understood everything) they struggled with the language during the experiment.
As mentioned before, those questions correspond to our exclusion criteria and were added to stay as close to the original study as possible.
Since a touchpad cannot provide the same information as a computer mouse, we exclude participants that did not use a mouse during the experiment.
In the original study, all participants used their right hand to operate the mouse, we thus exclude participants who report that they are using their left hand on the computer.
We exclude participants with a score less than 3 in the language comprehension rating to sort out decisions that are made by guessing because the english animal name or other instructions were not understood.
Optionally, participants can submit socio-demographic information and feedback. After the questionnaire is finished, they are thanked for their help and the experiment ends.

Measurements

We will keep track of the correctness of the participants' response as a discrete binary variable. In addition to that, we report the x- and y-coordinates of the computer mouse position sampled at a rate of 42Hz. The coordinates reflect participants' continuous trajectory of mouse movement during categorization.
Response time in milliseconds from clicking the button on the bottom until clicking one of the two categories in the top will be measured as well.
The binary variable typicality (typical, atypical) acts as a predictor (independent variable) while the x- and y-coordinates of the mouse movements together with their respective time points represent the outcomes (dependent variables).

References

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