Number of Value Levels to Be Learned Can Affect Short-Term Value Recall in Humans

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Abstract
Optimal decision making between multiple objects, requires accurate recall of each object's value. Value recall is known to be affected by a number of factors including the training duration and the number of objects, etc. Here, we hypothesized that the level of discrete values that has to be learned while other factors being equal impact recall. In this study, participants (n = 10) learned to associate abstract fractal objects with monetary rewards. The objects were divided into three groups with two, three or five reward levels, respectively. Importantly, the number of objects in each group, the dynamic range of values and the training duration were the same across the three groups and the low-level visual features were randomized between value categories. By the end of value learning, subjects were asked to indicate the value of each object using a sliding bar (unitary choice trials). Subjects' performance for all three groups were similar and not significantly different (2 level: 86.2%, 3 level: 87.7%, 5 level: 88.4%, $p>0.1$). Importantly, value memory tested around 2 hours later using the same unitary choice trials showed lower recall for the objects that belonged to groups with more reward levels (2 level: 84.6%, 3 level: 77.8%, 5 level: 64.2%, $p<0.05$). Our results suggest that all else the same, value resolution can affect value recall. It remains to be seen whether exposure to contexts with different value resolutions shapes subsequent choice behavior which may be suggestive of a framing phenomenon in our future studies.

Keywords: Value, Learning and Memory, Value Levels, Recall, Psychophysics

Introduction

Learning values of objects is necessary for humans and animals to fulfill their primary needs and to survive. For it is important to remember previously learned values when it comes to making decisions between a set of options. It has been shown that value memory depends on the procedure and duration of training (Farmani et al., 2024). Object value memory has large capacity for storing value of objects in humans (Farmani et al., 2022 and 2024) and primates (Ghazizadeh et al., 2018b). Objects may appear to be Good/Bad (with only two levels of value) or the value magnitude may be graded (Ghazizadeh and Hikosaka, 2021). When object values appear in a graded manner, the value resolution in the learning sets might have some kind of framing effect (Tversky and Kahneman, 1981) on memorizing object values in short-term. Most of the previous work concerned cases where subjects learned values of many objects associated with only two reward levels. Therefore, it is not clear if the memory capacity is affected by the number of reward levels independent of the number of objects.

To address this issue, we designed psychophysics experiments in which human subjects learn value of several objects in sets with different number of levels. To ensure that participants learned the exact value of objects, we frequently asked them about object values during training. An hour later, when we asked them about object values as a memory test, we observed different rates of value recall depending on the number of value levels in learning sets. Exploring the reason for this observation, we found that value recall is diminished for objects with intermediate values. As a consequence, retrieval rates are lower in sets that consist of more objects with intermediate values and this occurs in sets with more possible value levels during learning.

Methods

In this study, we designed psychophysics experiments and ten volunteer human subjects (7 female, age: 27.2 ± 1.8) performed the task. All subjects gave written consent to participate in the experiment. All subjects received monetary reward based on their performance at the end of the task. The task consisted of two phases; the training phase and the memory test phase. The memory test phase was performed about one hour after the training phase had started.

Objects

We used fractal objects with randomized low-level visual features from our previous studies (Ghazizadeh et al., 2018a). Each participant learned values of 22 fractals chosen randomly from a set of 100 fractals. In a 5-level block, subjects learn values of 5 fractals chosen randomly from {0,25,50,75,100}. Each value is assigned to exactly one object in a 5-level block. In a 3-level block, 6 fractals appear with values chosen randomly from {0,50,100}, with each value assigned to exactly two objects. In a 2-level block, 6 fractals appear with value either zero or 100 with each value assigned to exactly three objects.

Reward

Each fractal was assigned with a numerical value in a 0-100 scale. Value amounts were corresponded with monetary reward. Participants were informed that they would receive 10% of their sum score in one of the training blocks chosen randomly. Participants received reward realizations at the end of the task.

Task

The training phase consists of four blocks (Figure 1C). Values are offered either in 5 levels (two blocks), 3 levels (one block), or 2 levels (one block). Blocks are ordered pseudo-randomly in such a way that exactly one 5-level block occurs in the first two blocks and one in the last two blocks.

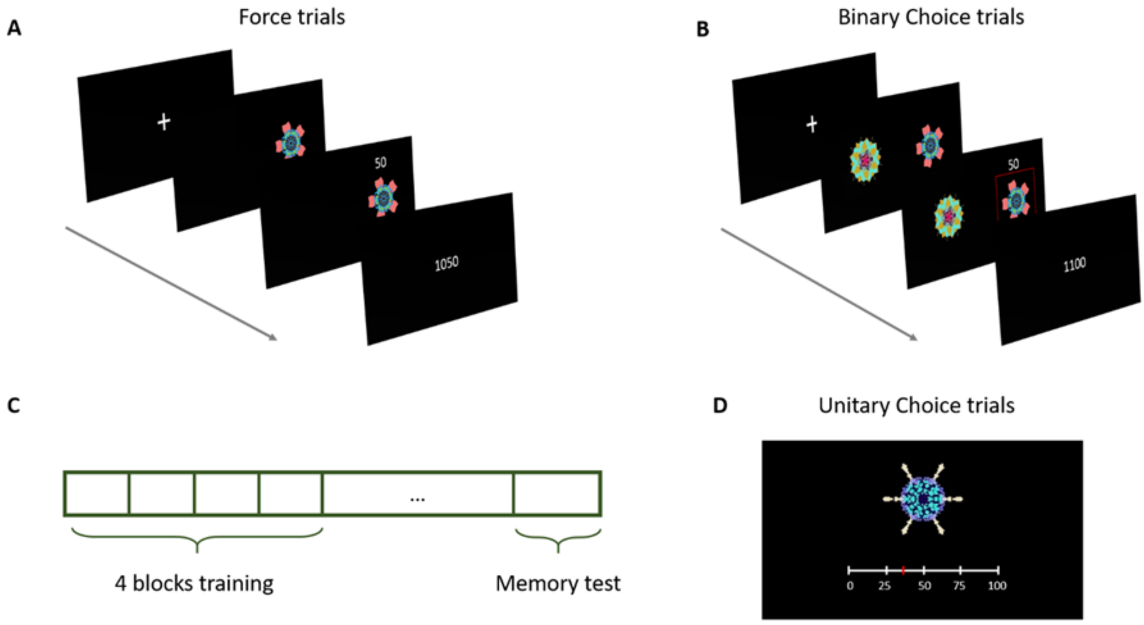

Figure 1. Task structure

During training, three types of trials force trials (**A**), binary choice trials (**B**), and unitary choice trials (**C**) appeared in random order.

Trials

During training, three types of trials (force trials, binary choice trials, unitary choice trials) appear in random order respecting a block design; in 6 successive trials, there is at least one binary choice trial and one unitary choice trial.

In *force trials*, one fractal appears at the left or right side of the screen. Subjects are trained to press the left/right arrow key on the keyboard, respectively. After the key press, object value appears above the fractal (500 ms). A black screen with a white cross at the center appears after each trial (500 ms) and separates consecutive trials (Figure 1A).

In *binary choice trials*, two objects with non-equal values appear on the screen and participants are told to choose the object with the higher value by pressing the left or right arrow key (Figure 1B). After the key press, the chosen fractal is surrounded with a red square and its value appears above the object (500 ms).

In *unitary choice trials*, one object and a slider appear on the screen (Figure 1D). Participants are told to choose the object value on the slider with a mouse click. The slider permits for continuous choice of value in the range 0-100 and has ticks at 0, 25, 50, 75, and 100.

Each fractal appears 8 times in force trials (4 times at the left and 4 times at the right of screen). Any binary combination of non-equal valued fractals in one block appear 2 times with reversed left/right objects. Value of each fractal is asked 3 times through unitary choice trials with three different initial cursor positions on the slider; at the beginning (0), center (50), end (100).

Memory Test

After an hour from the start of training, subjects answered the same unitary choice trials in random order repeated three times for each object. This stage served as the value memory test.

Data Analyses

Data from one subject was excluded due to low performance (less than 50 percent) in some training blocks.

Performance of subjects in binary choice trials was defined as the percentage of correct choices (choice of the fractal with higher value) in such trials. Performance in unitary choice trials was defined in the same manner. Chosen amounts were considered correct if their difference with the object value was less than 5.

Statistical significance of results was tested with Analysis of variance (ANOVA) with $p = 0.05$ as the significance threshold.

Results

Participants learned value of fractal objects in four blocks. In each block, values were learned either in 2,3, or 5 level steps. Blocks were ordered randomly for each subject. During training, in binary choice trials, two objects appeared and participants were asked to choose the fractal object with the higher value (Figure 1B). Subjects performance in these trials shows that values were learned properly in the training phase regardless of value level steps (2 level: 95.6% ± 1.5, 3 level: 95.1% ± 2.7, 5 level: 89.4% ± 1.5). Due to the random order of such trials, appearance of objects that were not learned in previous trials was possible and explains for non-perfect performance in these trials.

To ensure that subjects were learning exact values rather than their relative orders (ranks), we asked objects values explicitly in unitary choice trials (Figure 1D). In these trials subjects' performance was acceptable (Figure 2) and showed that subjects learned value amounts precisely (2 level: 86.2%, 3 level: 87.7%, 5 level: 88.4%, $p>0.1$).

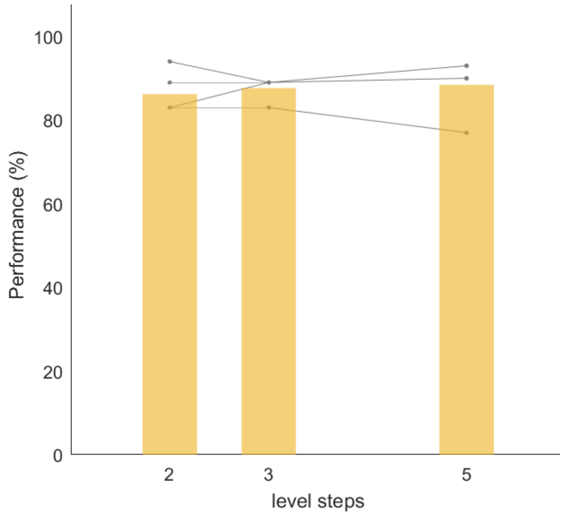

Figure 2. Performance in unitary choice trials during training

Subjects learned object values properly regardless of the number of value levels in training blocks. Data from individual subjects is plotted in grey.

To check whether subjects are treating values as mere numeric labels or feel their value, we looked at their reaction times in force trials. We observed that subjects choose higher-valued fractals faster (Figure 3). Although force trials are self-paced and only one option is available to choose, in the second half of each block that participants are aware of object values, reaction times decreased with increasing the object values from zero to 100. In comparison with zero-valued fractals, 100-valued fractals are chosen faster in all sets (Figure 3).

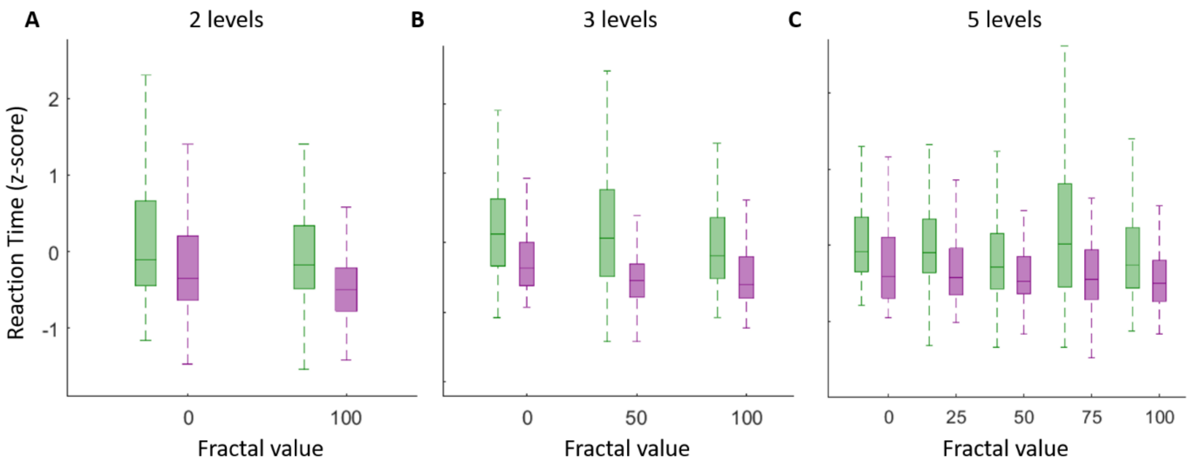

Figure 3. Reaction times in force trials show signatures of value learning

Time from fractal onset to key press in force trials in force trials in a set with two (A), three (B), or five (C) value levels. Green box plots correspond to reaction times in the first half of trials in each set and purple box plots correspond to the second half of trials. In the second half of trials (purple), higher-valued objects are chosen faster compared to zero-valued objects confirming effectiveness of the value learning paradigm.

Therefore, participants learned object values equally well in all blocks. However, when measuring value memory through the same unitary choice trials, we noticed that subjects' performance is significantly lower in objects within the 5-level blocks ((2 level: 84.6%, 3 level: 77.8%, 5 level: 64.2%, $p<0.05$, Figure 4).

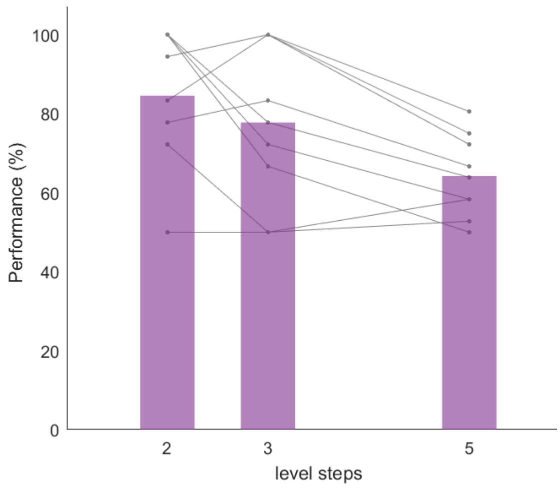

Figure 4. Performance in unitary choice trials during memory test

Value recall is affected by the number of value levels in training blocks. Data from individual subjects is plotted in grey.

We observed that the number of value levels in a learning block can affect value recall in humans. To investigate the underlying reasons of this effect, we measured value recall in all objects grouped by their absolute value. As demonstrated in Figure 5, the highest and lowest values are remembered better than intermediate values suggesting that the mechanisms for storing extreme values in memory differ from that for non-extreme values.

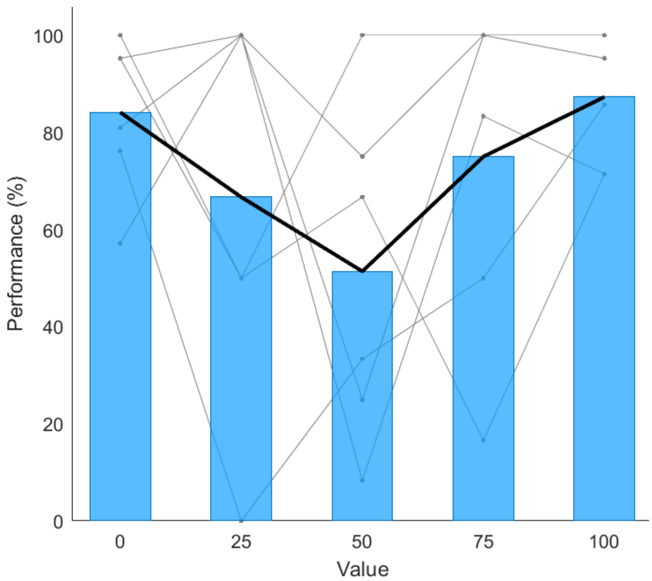

Figure 5. V-shaped performance in unitary choice trials after one hour

Average performance in memory test trials grouped by object value. Data from individual subjects is plotted in grey.

The V-shaped performance curve attains its minimum at 50 which is the average of object values in each set and overall. This effect can be studied more rigorously, in future studies.

Discussion

Humans and animals are motivated to interact with objects that are previously associated with reward. Object value memory is shown to depend on the learning process (Farmani et al., 2024). In this study, we asked whether value recall is affected by the number of value levels during learning. Our results suggested that objects values are remembered less clearly, as the number of value levels increased during learning. By means of psychophysics experiments with human subjects, we found that intermediate and extreme values are not remembered equally well. In fact, memory retrieval is a V-shaped curve. When the number of value levels increase, subjects are required to learn low values and high values as well as the intermediate values. However, in sets with 2 value levels subjects only need to learn low and high values. Weak recall of intermediate values results in lower performance rates in memory test for sets with higher value resolution. This can be improved with enhanced training procedures in future studies. Increasing the number of training trials could help to attain near perfect performance in all object sets.

The V-shaped curve observed in memory performance of object values may indicate that objects with the highest and lowest utilities for participants are less likely to be forgotten than the ones with medium values. This is in line with larger slope of the utility curve at extreme benefits or losses in prospect theory (Kahneman, and Tversky, 2013).

Memory is about storing information for later recall. The way information is encoded affects how well it is remembered later. It has been shown that when encoded through meaningful associations, information is remembered better in long-term. This effect often called *levels of processing*, indicates that if information is encoded on a deeper level, it is more likely to be remembered (Mcleod, 2007), suggesting that in the long-run mere repetition is not sufficient for making an experience, event, or a piece of information memorable.

Memory distortion is commonplace and is extensively observed and studied in humans (Roediger and McDermott, 2000). It has been shown that when remembering past events, humans exaggerate what matters to them most and ignore other details (Holzman and Klein, 1954; Suzuki, 1979). This effect known as *Leveling and Sharpening* is one form of memory distortion first introduced by Allport and Postman (1947). In the present experiment, one can argue that human subjects try to maximize their reward with the least possible effort. During decision making humans need to decide on which objects to approach and which ones to avoid. In this scenario, participants try to memorize high-valued and low-valued objects more accurately. This is consistent with the V-shaped performance of subjects during memory test. Leveraging and Sharpening is argued to depend on humans' personality and self-awareness (Holzman and Klein, 1954). It is not always a negative effect since the ability to capture and store highlights is important.

In the present task, fractals associated with 100 or zero values are the most and the least rewarding objects, respectively. Their extreme values suggest that these objects are the most important ones to memorize. One may argue that higher-valued objects are chosen more frequently during binary choice trials and are therefore better remembered after an hour. If frequency of choices was the reason for different recall rates, one would expect to see a monotonic increasing curve as a function of absolute value instead of a V-shaped relationship. In that scenario, the highest performance rate would occur for 100-valued fractals and the least performance rate would be associated with zero-valued fractals. But, this is not the case. We observed that 100 and zero-valued fractals are remembered equally well. As object values approach the mean value (50), value memory gets farther from perfect. Hence, objects are encoded with their values and not with the frequency of being chosen.

The 100 and zero values are not only the most salient (attention absorbing) objects but are also the first and last available values overall. It must be noted that when trying to memorize items in a list, humans remember the first and last item better than the other ones. In other words, the *serial position* of ordered pieces of information can affect recall (Ebbinghaus, 1885). Better memory for objects with 100 and zero values could be due to the order of their values. Further investigation is required to confirm or rule out the effect of these memory distorting factors in the present task.

Conclusion

Object value memory or the history of being associated with reward shapes our interactions with objects. Therefore, the accuracy of remembering object values is of utmost importance to humans and animals. Here, we demonstrated that the resolution of values one confronts during learning, can modulate value memory as a consequence of weak recall of objects with non-extreme values in high resolution contexts. We observed that the magnitude of object values can modulate value memory so the most and the least rewarding objects are perfectly memorized while objects associated with intermediate values are more likely to be forgotten. This may explain for humans idealistic and impulsive behaviors when they have many alternatives to choose from.

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