Decision Making in Mice (*Mus musculus*) Using Two-Dimensional Binary Choice Sets

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Abstract

Models of decision making have traditionally assumed a rational decision maker who will always try to maximize the return currency. However, various findings breach with the idea that decisions are made solely on the basis of rational, economic principles. One possible explanation for this breach is that the cognitive process of translating perceived values of an option from a physical to a cognitive scale happens in a nonlinear fashion. In this study we analyzed choice behavior in mice by investigating reward evaluation with respect to the dimensions "amount of reward" and "propability to receive a reward". To this end, we designed a two alternative forced choice experiment presenting individual mice with differently rewarding options using water from two water feeders as reward. We exposed the mice to four contexts with incongruent and neutral setups of reward dimension parameters to test if noneconomical behavior could be observed. Our results show that the mice did not use absolute reward evaluation. Furthermore, the mice were only efficient in making economically correct decisions when exposed to options that varied in volume but not in probability.

Introduction

The study of animal decision making is a useful method for the study of economic decision making in humans (Kalenscher and van Wingerden, 2011). Traditionally, decision making models have assumed a rational decision maker who will always opt for the most profitable option. In this context, profitability is understood as an optimization process of maximizing benefits and minimizing costs (Schuck-Paim and Kacelnik, 2002). In natural environments, options usually vary in multiple dimensions. For example, an animal might have to decide between a foraging option A offering vast amounts of food on an infrequent basis and a foraging option B offering few amounts of food with certainty.

A common approach that allows comparisons between options varying in

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multiple dimesions is the assumption that animals use value based decision making. In this model, the decision maker assigns weights to each dimension and derives a single value for each option. Options are thereby reduced to a common currency referred to as utility. Assuming a rational decision maker this concludes that the common currency will be maximized within the decision process. In evolutionary terms the common currency for an animal has been assumed to be Net Energy Gain (NEG) or Fitness Level. Therefore, an animal will always try to optimize its energy intake or reproductive opportunities (Stephens and Krebs, 1986).

However, recent studies have questioned the idea that humans and animals use rational based decision making. Various observations show that humans as well as other animals do not always make economical decisions (Cnaani et al., 2006; Kahneman and Tversky, 1979; Shafir and Yehonatan, 2014). To understand how noneconomical behavior can be explained, it is necessary to look at the cognitive aspects involved in the reward evaluation process. In order for an animal to evaluate rewards by value, it needs the ability to store obtained values in memory and it needs the ability to discriminate between options by the sensory information obtained. This requires a translation from the physical quantities of a reward to cognitive information (Nachev et al., 2013a,b). The relationship between physical and cognitive scales has been a major research area within the field of psychophysics and is has been found that the translation is often nonlinear (Nachev and Winter, 2012). Comparisons between options could occur on a physical or a cognitive scale which has to be accounted for, when forming theories of decision making. Context can have a strong impact on the value assigned to an option on a cognitive scale, while context would not affect the physical quantities of an option. For example, a food deprived animal presented with a specific food reward might later prefer this specific reward over a food reward of higher caloric potential. The information obtained in the food deprivation context might have been processed in a way so that the animal will continue to prefer this reward over other more rewarding options in the future. This example illustrates, that physical reward information are not sufficient to fully understand the processes involved in decision making. Context-dependent reward evaluation has been intensively studied in starlings as well as in hummingbirds and honey bees (Bateson et al., 2003; Kacelnik and Marsh, 2002; Pompilio and Kacelnik, 2010; Shafir et al., 2002).

Due to the insufficiency of the absolute reward evaluation model, various alternatives have been proposed. Comparative reward evaluation assumes, that animals base their decisions on a priority dimension and only use in dimension comparisons (Shafir et al., 1993; Shafir and Yehonatan, 2014). Comparative reward evaluation would explain noneconomic behavior because even though the animal might take overall caloric value into account, its decision might differ from the optimal decision due to the impact of the priority dimension. For example, it was shown that deciding beween nectar rewards in bumblebees is priorily influenced by sucrose concentration rather than by NEG (Cnaani et al., 2006).

One advantage of comparative decision making is that it requires less computational effort, thus reducing processing costs which could be beneficial for an animal. Comparative and context dependent reward evaluation offer possible explanations why objectively economic behavior is not always observed (Kahneman and Tversky, 1979; Shafir et al., 1993; Shafir and Yehonatan, 2014).

Since we cannot directly measure subjective cognitive representations of rewards, researchers have instead focused on measuring behavioral output (Nachev et al., 2013b). In order to broaden our knowledge of when and how animals behave uneconimically, it is necessary to study a broad range of species.

Mice are fairly closely related to humans, show similar brain organization and economic behavior. Therefore, studies with mice could provide valuable insights to human decision making processes (de Visser et al., 2011; Zschummel, 2014).

The hypothesis that we test in the present study is that mice do not use absolute reward evaluation as it has been observed in bumblebees, starlings, humans and other species. To this end, we designed a two-alternative forced choice (2AFC) experiment presenting the mice with two differentially rewarding options. The rewards were provided by two water feeders that differed in the probability to give water and the water volume of a single reward. Naive mice have been observed to prefer probability over volume (Nachev, personal communication). In the present study we used non-naive mice that had previously been used in similar experiments. Assuming a learned certainty of eventual food rewards within the laboratory context we expected the mice's preference of probability over volume to decrease. We exposed the mice to four different contexts creating incongruent and neutral parameter conditions. If mice used absolute reward evaluation and were able to distinguish between the relative intensities chosen for each dimension they should prefer the option that yielded the better average volume output. Each condition was tested for one day, followed by a reversal to avoid side biases. Our results are in accordance with our hypothesis and show that mice do not use absolute reward evaluation. Furthermore, mice decisions were only economically efficient when forced to decide between options that varied only within the volume dimension.

Methods

Experimental Setup

In our experiment we used 8 female non-naive laboratory mice of the strain C57Bl6/NHsd. The mice, which were 20 weeks of age, had been used for similar behavioral experiments before.

The mice were housed isolated in individually ventilated cages (IVCs). Each cage contained two water feeders which would be activated through nose pokes, while the water volume and reward probability could be programmed individually. The recorded information comprise the nose pokes on each feeder, together with a time stamp, the duration of each event and whether a reward was given or not. Further details on the cage setup as well as on the handling of the mice are found in Becker et al. (2016) and Clos et al. (2016). Differing from the experiments performed in those studies, we did not add any time delay or timeout. We also removed any separating walls between the feeders as we had observed them to cause strong left side biases.

Our experiment was designed, executed

and pre-evaluated as a collaborational work together with Sophie Leineweber, Falk Mielke and Nicola Vallon.

The experiment was designed so that the reward volumes differed between the two feeders. However, relative volume intensities were kept constant throughout the experiment and only the reward probabilities were varied instead. For the reverse experiments we swapped the parameters between the left and right feeder. The general idea was to subject the mice to four different setups in regard of the relative intensity ratio for volume $I_r(v)$ and probability $I_r(p)$. In all our setups the probability dimension opposed the volume dimension so that the greater reward volume was combined with the lower probability and vice versa. We created three incongruent setups, where the $I_r(p)$ differed from the $I_r(V)$ and one neutral setup where the $I_r(p)$ was equal to the $I_r(V)$ (Table 1). The relative intensities were calculated on the basis of equation 1.

$$I_r(x) = \frac{|x_1 - x_2|}{\frac{x_1+x_2}{2}} \tag{1}$$

with x: conditions on the different feeders

We decided on the relative intensities to use in accordance with a psychometric curve obtained from previous experiments (Nachev and Rivalan, personal communication), fitted with a Weibull distribution (Weibull, 1951) (Figure 1).

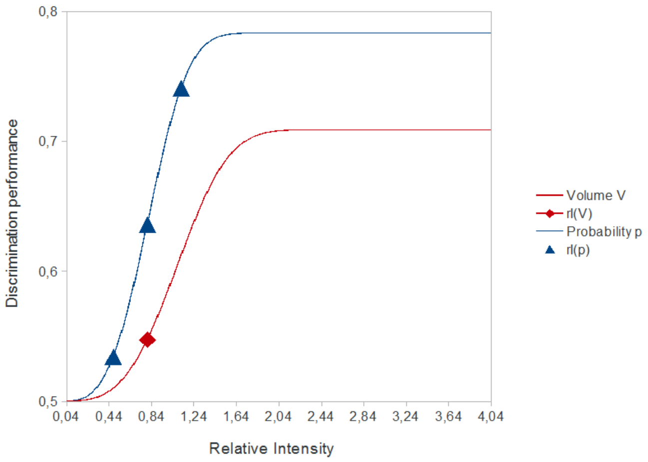


Figure 1: Psychometric function based on which the relative intensities were chosen. The relative intensities were chosen to cover the slope of the function, chosen values are indicated by different symbols for both used dimensions.

Table 1: Experimental setup, chosen values for the relative dimensions for volume and probability.

$I_r(V)$	$I_r(p)$	$I_r(p)/I_r(V)$	Setup
0.8	0.0	0.0	incongruent
0.8	0.5	0.6	incongruent
0.8	0.8	1.0	neutral
0.8	1.1	1.4	incongruent

Experimental Schedule

The mice were split into two groups of four mice, participating on our experiment for nine days one group at a time. Before the actual experiment started, the mice were given one day to adapt to their cages, without any differences on the reward volume between the feeders and a probability of one on both. Afterwards, the four setups were applied in a random order thus that ascending and descending orders of relative intensities were avoided and no mouse would get the same setup as another on the same day. Each setup was followed by its reversal the next day, to avoid side biases.

For the first group of mice, reward probabilities between 0.26 and 0.9 were chosen. Since we observed a lack of learning behavior we lowered the probabilities for the second group to values between 0.1 and 0.35, hoping to thereby enforce learning behavior. The exact values are listed in Table 2.

Table 2: Values for volume and probability for both groups of mice

Feeder	Volume [ml]	Group 1 Probability	Group 2 Probability
1	6	0.3	0.15
2	14	0.3	0.15
1	6	0.5	0.25
2	14	0.3	0.15
1	6	0.7	0.35
2	14	0.3	0.15
1	6	0.9	0.35
2	14	0.26	0.1

At 4 pm each day the new set of experiments was started, the mice then had water access under the listed conditions for 18 hours, during their nocturnal phase. To better understand the behavior of our mice, we captured two mice on video under infrared light during one night.

Data Analyses

We collected and distributed our data using an SQLite database (Hipp et al., 2015) as well as a GitHub account (GitHub Inc., 2015). Data Analysis has been done using R (R Core Team, 2015).

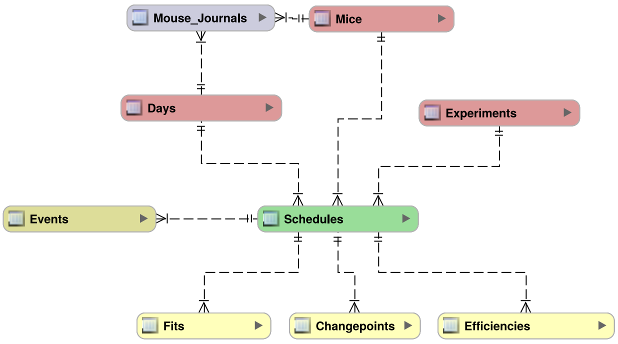


Figure 2: Structure of the database used for data analysis, which has been set up by Falk Mielke. The data as well as our analysis are accessible through GitHub as referenced below.

The collected data can be accessed via `https://github.com/falkm/mus_oeconomicus`. The structure of the database is presented in Figure 2.

Results

Throughout the experiment all mice showed strong side biases while the side preferences varied for different mice. The alteration of the settings for the second group of mice even increased those biases. Mathematically, we broadly eliminated them by averaging over reverse experiments. However it is not possible to fully dispose of other influences besides the different rewarding options. As can be seen on our video footage, the mice regularly poked repeatedly at the same feeder or sometimes switched freely between feeders, as there were no walls to hinder them. This behavior has been captured on video (see Appendix). In consequence we excluded events which occurred within a threshold of 4 seconds from the prior event.

Learning behavior

We had planned to analyse the learning behavior by calculating the cumulated water intake over time or trials for the different mice under the varying settings. However, in the majority of cases, our results do not indicate a clear learning behavior over one testing period (one day each).

Instead, we did a changepoint analysis, using the approach proposed by Gallistel et al. (2004), by firstly calculating the cumulated sum of events at the feeder with the higher water volume (V_+) over trials, then calculating the change points and subsequently the slopes between them (Gallistel et al., 2004). A changepoint in this context is the point where the behavior changes, indicated by a change in the slope. It is calculated for each point as the earlier point that deviates maximally from the straight line between the start of the record and the latest point. For this calculation the R function "cp_wrapper" from the package "cpdetectorr" has been used (Nachev, 2015).

We applied a binominal test with a decision criterion of p=0.15. The slope between the last two change points (the last relevant slope) was used for further analysis. As an event at the feeder V_+ counts plus one and an event at the feeder V_- counts as zero, ideally a steep slope would be expected if the volume favored side provides the (objectively) better option and a flat slope otherwise. An exemplary fit is illustrated in Figure 3.

For further analysis, we averaged the respective last slopes over those from the reversed experiments and then plotted our data for the $I_r(p)$ (Figure 4). Even if single mice adapted diversely to the different conditions, overall no significant variance can be detected (using ANOVA, binominal). A mean slope around 0.5 indicates that the feeders on average had been chosen randomly. There is no exception for any condition. However, the data are widely scattered for any condition that was tested, and individual mice reacted differently to the same conditions.

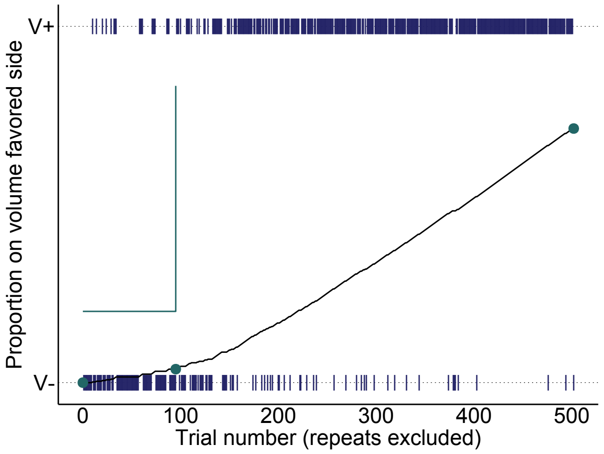


Figure 3: Exemplary changepoint analysis with equal probability on both feeders, cumulated sum of events at volume favored feeder. In this case, a change in the mouse's behavior after approximately 100 trials can be observed. This is reflected in the stepwise learning curve.

The absence of a clear learning effect in conjunction with the strong side biases led us to examine the explorative behavior of our mice over an expanded period of time, supposing they might integrate over longer timescales than the duration of one experimental setting (one day).

Therefore, for each day and each mouse, we calculated the ratio of events at the less frequented feeder to events at the preferred one. Then for each day, counting the day a mouse started to participate in the experiment as day one, we averaged over the event ratios from the different mice. Figure 5 illustrates how these mean ratios changed over the days of the experiment.

A higher mean events ratio means that the mice were more explorative that day. As illustrated by Figure 5(a), if averaged over all 8 mice, the mean events ratio decreases over the days of experiment, meaning that the mice explored less over time. In Figure

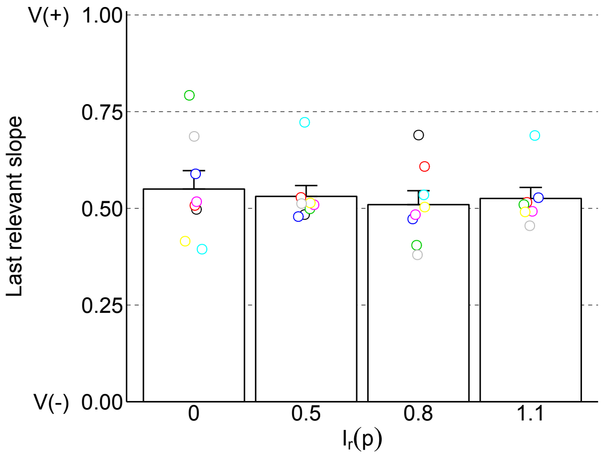
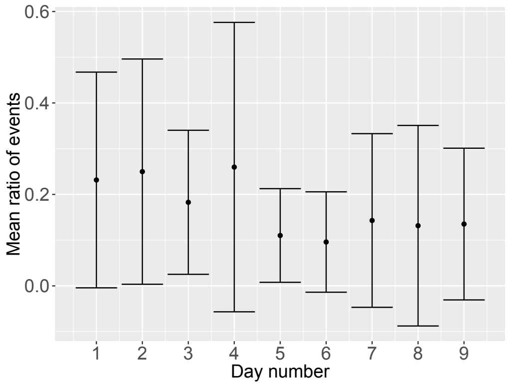
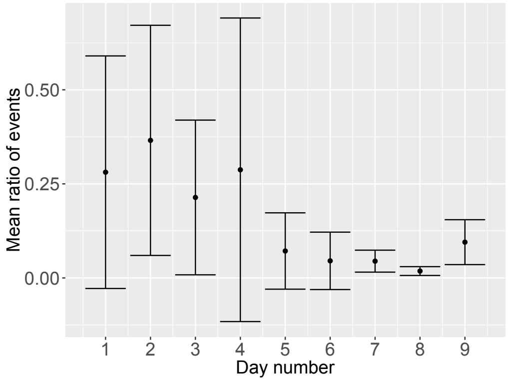


Figure 4: Slope analysis for different $I_r(p)$. Dots represent single datapoints, each color represents one mouse. The economical choices would have been: Feeder V_+ for $I_r(p) = 0.0$ and $I_r(p) = 0.5$ (slope > 0.5), feeder V_- for $I_r(p) = 1.1$ (slope < 0.5) and both feeders equally for $I_r(p) = I_r(V) = 0.8$ (slope $\approx$ 0.5). Nonetheless no significant variance could be detected (tested with ANOVA). A mean slope around 0.5 indicates that the feeders on average had been chosen randomly.

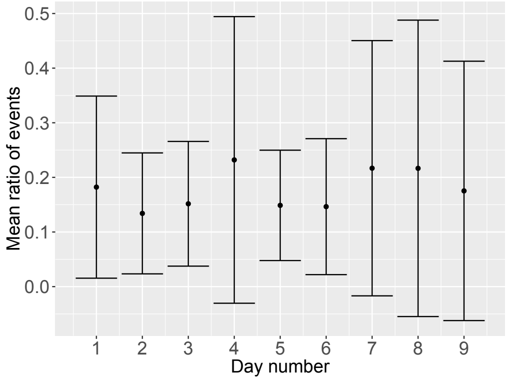
5(b) and 5(c) the two groups of mice are presented separately. Since there were only 4 mice in each group, no statistical approaches can be made for those two separate groups. Even so, we wanted to examine the behavior of each group because the lower probabilities, which have been used as parameter settings in the second group, might have influenced the mice's behavior crucially. The plots indeed indicate that group 1 is mainly responsible for the decrease over time in 5(a) while no clear conclusion on the explorative behavior over time for group 2 is possible. All in all, the mean ratios for group 2 are lower than in group 1 and the explorative behavior possibly even increased over time.



(a) Averaged over all mice



(b) Averaged over group 1



(c) Averaged over group 2

Figure 5: Exploration behavior over days of the experimental phase, illustrated by the ratios of events and their standard deviation. (a) Events ratio - averaged over all 8 mice - decreases over the days of experiment. (b) Events ratio averaged over the 4 mice from group 1, who seem to be mainly responsible for the decrease over time in (a). (c) Events ratio averaged over the 4 mice from group 2. No clear tendency over time, mean ratios are lower than in group 1.

Efficiency

Due to the lack of a clear learning effect, we decided against a psychometrical anaysis. Instead we calculated the efficiency of the mice under the different reward parameter conditions, regarding the dimensions Volume and Probability as well as the combination of the two dimensions, Volume×Probability.

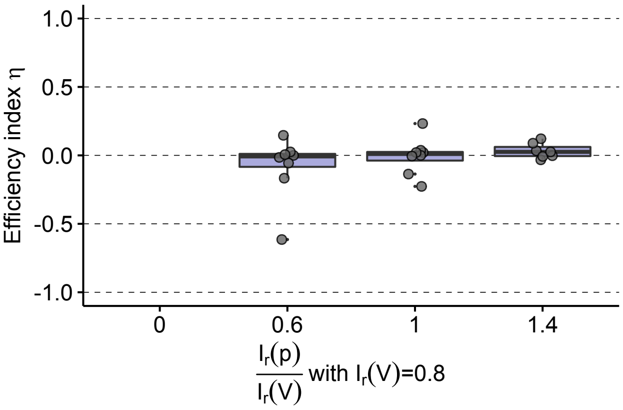
To calculate the efficiencies, we first calculated the sum of the infimum, supremum and the actual drinking performance over the events for volume, probability and the combination of both (volume×probabiliy). The infimum being the lowest possible value the mouse might have chosen, the supremum being the highest possible value and the actual drinking performance being the option the mouse actually did choose. We then calculated the efficiency index using equation 2. A high efficiency index indicates that the mice did prefer the better option in regard to the chosen dimension, a negativ index indicates that the mice prefered the other one while an index around 0 indicates that the mice treated both options equally.

$$\eta(x) := 2 \times \frac{x - inf(x)}{sup(x) - inf(x)} - 1 \qquad (2)$$

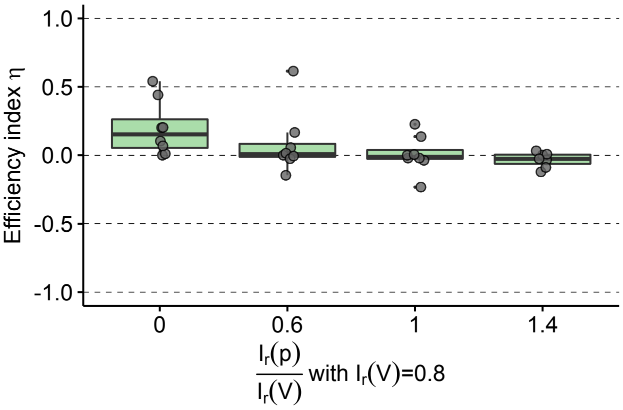
with x $\subset \{V, p, Vp\}$

The results are presented in Figure 6.

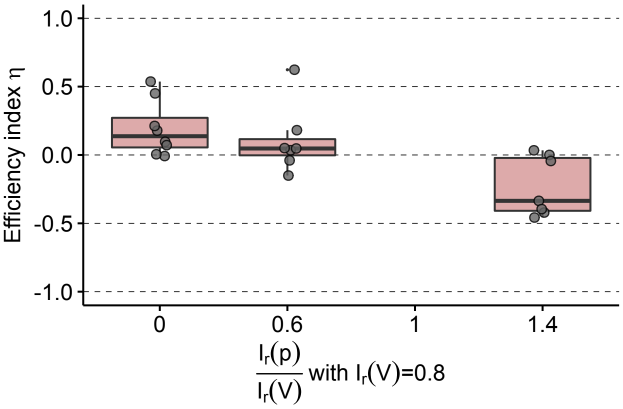
While there is no significant difference in the efficiency index, in regard to the dimension probability - for each $I_r(p)/I_r(V)$ the index stays around 0 - there is a difference in regard to the dimensions volume and volume×probability. The smaller the $I_r(p)/I_r(V)$, which means an $I_r(p)$ near 0, the more efficient were the mice in regard to the dimension of volume, while they



(a) regarded dimension: probability



(b) regarded dimension: volume



(c) regarded dimension: volume×probability

Figure 6: Efficiencies for different $I_r(p)/I_r(V)$, regarding (a) probability, (b) volume and (c) volume×probability. The results indicate that the mice treat the dimension of probability randomly and only distinguish for volume if $I_r(p)/I_r(V) \approx 0$. Regarding the combined dimensions, the mice are highly inefficient, when $I_r(p)/I_r(V)$ is highest.

started choosing randomly if the $I_r(p)$ increased. Regarding the combined dimensions volume×probability this means the mice have been efficient for a $I_r(p)/I_r(V)$ around 0 but are highly inefficient for a $I_r(p)/I_r(V)$ around 1.4 where the $I_r(p)$ is largest. Nonetheless, the data again are widely scattered and single mice performed differently.

Discussion

Our findings support the initial hypothesis that mice do not use absolute reward evaluation. If so, they would have been expected to choose the altogether more profitable option more frequently throughout all tested conditions. However, as our efficiency analysis shows (see Figure 6), this was not the case. Not choosing the economically correct option more often than other options based on a universal "currency" has also been observed in other species (Bateson et al., 2003; Cnaani et al., 2006; Shafir et al., 2002). The universal currency to compare different options across various dimensions is usually NEG, as is the case for our experiments, because the mice only eat when having access to water.

Slope analysis revealed that, on average, all mice did choose both available reward options as if by chance and independently from relative intensity of probability. This observation was also apparent in the efficiency analysis, solely when probabilities of both feeders where equal did the mice choose the economically more profitable option more frequently and thus achieved an above average total water intake. This behavior implies that, for equal probabilites, they were able to discriminate between the offered options and identify the more rewarding choice. As this was not the case for the other settings, we could assume that our mice were not able to discriminate the offered choices when probability came into play. This unability could be due either to the introduction of another dimension or, in particular, that this dimension was probability. However, in earlier experiments mice were able to differentiate between choices that differed in probability (Zschummel, 2014; Nachev and Rivalan, personal communication). Another explanation for the lower efficiencies associated with the probability dimension could be that the mice were able to discriminate between the offered options, but the differences were not relevant to them. However, it should seem more reasonable to assume that discriminating between probabilities rather than differing volumes would be important to mice, as the water sources encountered in natural environments do not require a good ability to discriminate volume due to their usually large amount of water (Zschummel, 2014).

Alternatively, the observed behavior could have been driven by influences unrelated to our setup and thus uncontrollable by us. Such influences can rarely be ruled out completely when studying mice, as they are complex animals, though well-studied, and their behavior is often obscure.

It is noteable that the mice tested in the first week explored the offered choices more in the earlier days of testing, with an increasing side bias towards the end of the experimentation phase (Figure 5b). The mice tested in the second week were less explorative altogether and did not show a decrease or increase in their exploration behavior over time. The higher exploration habit in the mice of week 1 might indicate that they integrated the rewards over a longer period than one day and came to choose one favorite feeder after some time.

A possible reason for the differing exploration behavior between the two groups could have been the altered conditions. In the first week, the mice might not have felt pressured enough to choose a preferred feeder, because they received sufficient water from both feeders regardless of treatment. In the second group, however, due to much lower probabilities the pressure to select an option was considerably higher and therefore the mice from week 2 might have been forced to reconsider their choice more often. Another strategy which could be considered influential here is win-stay; a more explorative behavior during the beginning of an experimental phase, as has been observed for the mice from week 1, has been found for rats in an earlier study (Moustgaard and Hau, 2009). For the mice of the second week, which had already been exposed to another choice-experiment in the prior week, it could be possible that they had already developed a win-stay strategy during the preceding experiment, which they applied in our experiment. However, as the mice in general did not perform well in discriminating between offered options and thus choosing the more rewarding one, other factors have to be considered. Side preferences were apparent in all mice, but do not generally distort the results as long as sampling still occured - assuming, of course, that the mice based their decisions on the used dimensions.

Still, to reduce side bias and enforce a stronger need to choose between options, the initial short walls between the nose poke-holes could be reintroduced to separate each hole and another short wall could be added instead of the long wall from the initial setup. This way, the mice would not be able to just sit in front of the feeders and switch between them without much effort. Other changes to increase the physical effort for the mice to reach the feeders could be considered, e. g. placing the feeders further apart or making them less accessible by placing them higher up. This way the mice would have to climb up first (which they are able to, as can be seen in the video footage) and therefore would require much more effort and energy to access the feeder, which could presumably lead to a greater desire to make the economically right choice. Additionally, to prevent repeated nose pokes, a delay of rewards rather than probability could be introduced, or, an activation key added, resultinh in the necessity to carry out another activity first to activate either one of the feeders, e. g. another poke hole located somewhere else in the cage.

Furthermore, future studies should include congruent settings, as this might shed light on the discrimination ability of mice regarding different dimensions. If mice still do not perform above average with congruent settings, this would mean that the lower efficiency for all settings including a relative intensity of probability over zero in this study, is due to the introduction of another (random) dimension. Since we do not know if the underlying reason for the lacking efficiency regarding all settings including a relative intensity of probability over zero, is the introduction of the dimension ‘probability’ or only the introduction of another dimension, the mice should be tested with several different dimensions. To conduct a psychometric analysis, both used dimensions should be tested with congruent conditions, with the relative intensity for one dimension set to zero constantly, while varying the I_{rel} of the other.

Keeping the mice in single cages could

have also influenced them in some way; on the one hand, they were not in competition with other mice for the water rewards, which might have led them to decide more freely. On the other hand, they could still see the neighboring mice through the plastic walls of their cages which might have had an influence. Furthermore, mice are social animals, therefore keeping them in single cages might affect their (choice) behavior.

Summary

As hypothesized earlier, our results show that mice do not use absolute reward evaluation. To find out, if mice can superiorly discriminate volume rather than probability or if incongruent conditions or the mix of two dimensions blocked the ability to discriminate proability, further research is necessary.

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Appendix

Video

`http://amor.cms.hu-berlin.de/~mielkefa/Sem9/CEB/20151208_165418_Mouse83all.mp4`

- At 10:40 repeated nose poking behavior and feeder changing can be observed.

Source Code

The relevant source code for this paper accessed through `https://github.com/Claartje/ceb_paper_1/tree/master/paper/relevant%20Code`

The code for the calculation of the mean events ratios is given as an example below:

```
############### Connection to database - Code from Falk Mielke ###############
## in this example, the dplyr way is chosen.
require('dplyr')

##### database connection #####
## go to the folder of the current file
setwd(dirname(parent.frame(2)$ofile))

## load the SQL interface helpers
source('../../database/SimplerSQLQuery.r')

## connect the database, in this case you choose to return a dplyr tbl object
sql_connection <- SQL_TBL$new(drv = RSQLite::SQLite(),
dbname = "../../database/data.db")
if(!sql_connection$connected) print ("something went wrong! no connection.")

# print(sql_connection$tables)

## load the tables with master data
experiments = sql_connection$LoadTable("Experiments")
schedule = sql_connection$LoadTable("Schedules")
days = sql_connection$Run("SELECT day_nr,
start_date,
block FROM Days;") # alternative: run an SQL query

## load the data table
events = sql_connection$LoadTable("Events")
events$date_time <- as.POSIXct(strptime(events$date_time, "%Y-%m-%d %H:%M:%S"))
# (unfortunately, SQLite is incapable of reliable date/time handling.
# Was saved as string.)
```

```

mice = sql_connection$LoadTable("Mice")

## when everything’s done with SQL:
sql_connection$Close()

############### Claculate ratio of events - Code from Clara Jongen ###############
#merge tables
alldata<-merge(experiments,schedule)%>%
merge(days)%>%
merge(events)%>%
merge(mice)

#Count Number of events
data<-alldata%>%
filter(exclude==F)%>%
group_by(day_nr,mouse_nr,side)

eventsSummary<-summarise(data, length(event_duration_s))

#filter for events on left and right side
eventsLeft<-eventsSummary%>%
filter(side=="l")%>%
group_by(day_nr,mouse_nr)

eventsRight<-eventsSummary%>%
filter(side=="r")%>%
group_by(day_nr,mouse_nr)

####Calculate ratio events
# divide number of events on less prefered side
# through number of events on prefered side

eventsRatio<-(ifelse(eventsLeft$‘length(event_duration_s)‘>
eventsRight$‘length(event_duration_s)‘,
eventsRight$‘length(event_duration_s)‘/eventsLeft$‘length(event_duration_s)‘,
eventsLeft$‘length(event_duration_s)‘/eventsRight$‘length(event_duration_s)‘) )

eventsRatio<-data.table(cbind(eventsLeft$day_nr,eventsLeft$mouse_nr,eventsRatio))
names(eventsRatio)[1]<-c("day_nr")
names(eventsRatio)[2]<-c("mouse_nr")

#split tables for mice of first and second week
eventsRatio_mice1<-eventsRatio%>%
```

```
subset(mouse_nr==1|mouse_nr==2|mouse_nr==3|mouse_nr==4)%>%
mutate(day_nr=day_nr-1)
eventsRatio_mice2<-eventsRatio%>%
subset(mouse_nr==5|mouse_nr==6|mouse_nr==7|mouse_nr==8)%>%
mutate(day_nr=day_nr-9)

###calculate mean events ratios
#for mice of first week
mean_mice1<-eventsRatio_mice1%>%group_by(day_nr)%>%
summarise(mean=mean(eventsRatio),
st_deviation=sd(eventsRatio))%>%
mutate(lower=mean-st_deviation,
upper=st_deviation+mean)

#for mice of second week
mean_mice2<-eventsRatio_mice2%>%group_by(day_nr)%>%
summarise(mean=mean(eventsRatio),
st_deviation=sd(eventsRatio))%>%
mutate(lower=mean-st_deviation,
upper=st_deviation+mean)

#calculate mean ratio over mice of all weeks
meanMice<-full_join(eventsRatio_mice1,eventsRatio_mice2)%>%
group_by(day_nr)%>%
summarise(mean=mean(eventsRatio),
st_deviation=sd(eventsRatio))%>%
mutate(lower=mean-st_deviation,
upper=st_deviation+mean)

#########Plot Data################
require('ggplot2')

# Plot for all mice

meanMice %>% ggplot(aes(day_nr,mean)) +
xlab("Day number") +
ylab("Mean ratio of events") +
scale_x_continuous(breaks = 1:9) +
geom_point()+
geom_errorbar(aes(ymin = lower,
ymax = upper))->meanMicePlot
print(meanMicePlot)
ggsave( sprintf("meanMice.pdf")
, plot = meanMicePlot
```

```
, width = 16
, height = 12
, units = "cm"
, dpi = 150
, device = cairo_pdf
)

#Plot for mice of first week

mean_mice1 %>% ggplot(aes(day_nr,mean)) +
xlab("Day number") +
ylab("Mean ratio of events") +
scale_x_continuous(breaks = 1:9) +
geom_point() +
geom_errorbar(aes(ymin = lower,
ymax = upper))->meanMice1Plot
print(meanMice1Plot)
ggsave( sprintf("meanMice1.pdf")
, plot = meanMice1Plot
, width = 16
, height = 12
, units = "cm"
, dpi = 150
, device = cairo_pdf
)

#Plot for mice of second week

mean_mice2 %>% ggplot(aes(day_nr,mean)) +
xlab("Day number") +
ylab("Mean ratio of events") +
scale_x_continuous(breaks = 1:9) +
geom_point() +
geom_errorbar(aes(ymin = lower,
ymax = upper))-> meanMice2Plot
print(meanMice2Plot)
ggsave( sprintf("meanMice2.pdf")
, plot = meanMice2Plot
, width = 16
, height = 12
, units = "cm"
, dpi = 150
, device = cairo_pdf
)
```

List of Figures

1 Psychometric function 4
2 Database 5
3 Exemplary changepoint analysis 6
4 Slope analysis 7
5 Exploration behavior over time 7
6 Efficiencies for different $I_r(p)/I_r(V)$ 8

List of Tables

1 Experimental setup 4
2 Values for volume and probability for both groups of mice 5

Role Assignment

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