**Preference consistency relies on hippocampal function: Evidence from mediotemporal lobe epilepsy**

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**Introduction**

The notion that our preferences draw on past experience and hence memory should not be controversial. Memory representations of past choices and their consequences allow organisms to learn what sources of food provide optimal nourishment and which predators and other dangers to avoid, ensuring our survival and well-being by informing future preferences. To the extent that such information has great generality over time, it even gets incorporated into a species’ genetic blueprint, its collective memory record, resulting for example in hardwired fear of snakes in chimpanzees and humans.

The field of economics has treated preferences as a primitive in its influential axiomatic models of choice (e.g., von Neumann & Morgenstern, 1952). Perhaps as a result, the connection between properties of memory and judgment and choice has historically been ignored, with only a few exceptions (Weber, Goldstein, & Barlas, 1995). More recently, memory considerations have played a more prominent role in explanations of judgement and decision-making (JDM) phenomena attempting to leverage what we know about memory to provide insight into the processes underlying known decision phenomena (Reyna et al 2003; Schneider 2003).

Memory processes provide entry points for psychological models of judgment and choice, in addition to the important role of attentional and perceptual processes that have resulted in models such as prospect theory (Kahneman & Tversky, 1979). As reviewed by Weber & Johnson (2009), both memory encoding and retrieval processes influence judgment and choice in multiple ways. If preferences are often constructed (see Lichtenstein & Slovic, 2006), an insight that may arguably be psychology’s most successful export to economics, then memory processes can be expected to play a major role in this construction (Weber & Johnson, 2006). Query theory (Johnson et al, 2007; Weber et al., 2007) suggests that decision-makers consult their memory (or external sources) with automatic and implicit queries about the choice alternatives, in particular arguments for choosing one or the other, i.e., their merits or liabilities. Past experiences and other associations provide the basis for such evaluation.

One way to show that memory for past events plays a role in choice is to show that important choice characteristics are impaired in individuals who are known to have memory encoding or retrieval deficiencies. Memory of past experiences and imagining future experiences activate a common set of brain regions that include the hippocampus (Schacter & Addis, 2007), and these functions are impaired in patients with hippocampal damage (Klein et al., 2002). Thus patients with hippocampal sclerosis may be expected to show impaired preference construction.

To examine this, we employ a simple paradigm, binary choices among simple food products. Our basic measure is choice transitivity, whether or not choices among these options are consistent across choices. For example if a person chooses A over B, and B over C, transitivity implies that they must pick A over C (Samuelson, 1938). Transitivity has been a central measure in early work in decision-making (Tversky, 1969), and recent work examining preferences in neuroscience (Camille, Griffiths, Vo, Fellows, & Kable, 2011; Fellows, 2006; Fellows & Farah, 2007; Kalenscher, Tobler, Huijbers, Daselaar, & Pennartz, 2010) and consumer choice (Lee, Amir, & Ariely, 2009). One reason for focusing on transitivity is that it is the central as the General Axiom of Revealed Preference and is necessary and sufficient for value maximization (Houthakker, 1950). Without GARP, one cannot be truly maximizing value. Transitivity of preferences is embraced by most individuals as a desirable choice attribute, i.e., most people will change intransitive choice patterns to transitive ones, when their inconsistency in choice at different points in time is pointed out to them (Birnbaum & Guitierrez, 2007).

Prior research has used patients with ventromedial frontal lobe damage, areas known to be involved in the expression of value, to the frequency of intransitivities both for gambles (Camille et al., 2011) and preferences for food, colors, and people (Fellows & Farah, 2007). The latter work included an important control: An increase in intransitivity was not observed for perceptual judgments, suggesting that preferential tasks are uniquely affected.

Our task examines binary choices among pairs of 20 commonly available candy bars, a product that would be familiar and interesting to participants. We include a control judgment, asking respondents which number was bigger.

**Methods**

Thirty-one patients with clinically diagnosed hippocampal sclerosis from the presurgical program at the Department of Epileptology in Bonn were included in the study (MTL). As control groups, thirty patients with extratemporal lobe epilepsy (ETL) and thirty healthy control subjects (CON) were comprised. The study was approved by the local ethics committee of the University of Bonn and all subjects gave their written informed consent. The three groups did not differ with respect to age or gender (see Table X for details).

*Behavioral experiment*

Each subject made a series of binary choices on a computer between pairs of candy bars drawn randomly out of twenty, with each combination presented once, resulting in 190 choices. This procedure was adapted from Lee et al. (JCR, 2009). A choice was counted as inconsistent, if chocolate bar “A” was preferred over “B” and “B” over” C”, but “C” over “A”. We performed an additional control task in which subjects were presented with numbers from one to twenty and had to perform a judgment on which number was larger. Subjects received the choice of one random trial as additional payment to a participation fee of 10 €.



Fig 1. Three example trials of the binary choice experiment. Subject performed a choice of their preferred chocolate bar in each trial. The timing of the stimulus presentation and choice was self-paced.

*MR sequence and analysis*

For a subgroup of the patients with hippocampal sclerosis, a 3D-T1 weighted high-resolution data-set (MP-RAGE, voxel size 1x1x1mm, repetition time 1570ms, echo time 3.42ms, flip angle 15°, field of view 256mm x 256mm) was available for volumetric measurement of the hippocampus. This was done in a fully automated manner by means of the FreeSurfer image analysis suite (Version 5.1.0, Martinos Center, Harvard University, Boston, MA, U.S.A.) ([Fischl *et al.*, 2002](#_ENREF_12); [Fischl *et al.*, 2004](#_ENREF_13)), which is documented and freely available for download online (<http://surfer.nmr.mgh.harvard.edu/>). Because of the high variance in hippocampal volume between individuals, we used a laterality index of hippocampal volume as a proxy for unilateral hippocampal damage (*abs((Hippovol-Left – Hippovol-Right)/(Hippovol-L+Hippovol-R)*). Only subjects with unilateral hippocampal sclerosis were included in this analysis, because bilateral atrophy cannot be quantified by this measure.

*Statistical analysis*

Statistical analyses were performed using SPSS Statistics 21.0 for Windows (IBM, Armonk, NY, U.S.A.) and R (Version 3.0.2) for Mac. All values throughout this report are given as mean unless otherwise stated. A probability (p) value ≤ 0.05 was regarded as statistically significant using two-tailed tests. Statistically significant differences in the figures and tables are marked with asterisks: \*p ≤ 0.05, \*\*p ≤ 0.01, and \*\*\*p ≤ 0.001.

*Counting intransitivities*

The binary choices each subject made were transformed in to a matrix of triplets because the detection of an intransitivity as defined above requires three trials. Each matrix consisted of 1140 possible combinations of 3 of 20 bars. A triplet was marked as indicating intransitivity either if A was chosen over B and B was chosen over C yet C was chosen over A or if B was chose A and C was chosen over B yet A was chosen over C. The percent of intransitivities is then calculated using the number of triplets marked as indicating intransitivity.

**Results**

Patients with hippocampal sclerosis showed an increased number of inconsistent choices compared to the two control groups (Fig. 2; mean percentages: MTL: 6.80%; ETL: 4.45%; CON: 2.81%; median percentages: MTL: 4.91%; ETL 3.25%; CON: 3.03%; Kruskal-Wallis-Test of independent groups p<0.001). The two controls group did not differ significantly from each other (Wilcoxon rank sum test p = 0.193).[[1]](#footnote-1)

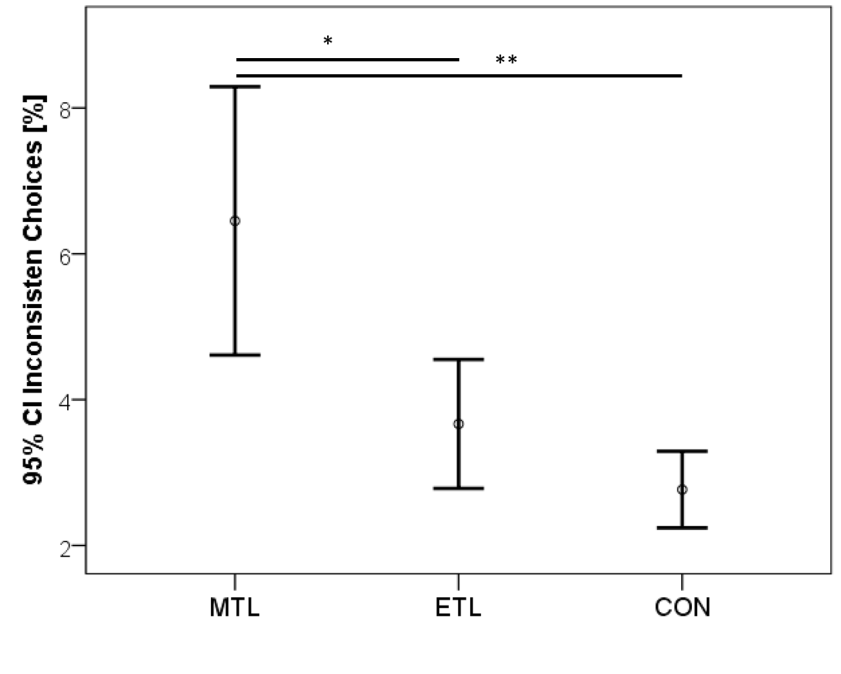
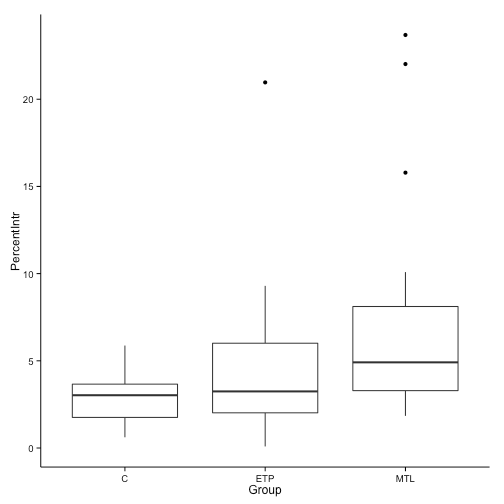


Fig. 2. Mean and 95%CI of the percentage of inconsistent choices for the three subject groups. \* p<0.05; \*\*p<0.01



The ratio of compromised hippocampal volume to total volume was significantly correlated with the amount of inconsistencies (Fig.3; spearman-rho = 0.761; p<0.001; n=16).

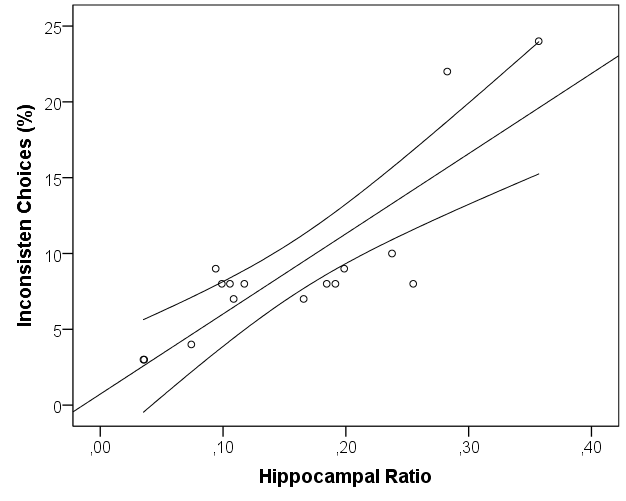


Fig 2. Correlation of hippocampal asymmetry (as a marker for unilateral atrophy) and percentage of inconsistent choices with 95% CI of the mean. rho=0.761, p<0.001

In the control task all groups did very well but the ETL group was significantly worse than the control group (percentage of errors: MTL: 0.81%; ETL: 1.17%; CON:0.07%; p<0.001 Kruskal-Wallis test for independent groups; MTL vs. ETL n.sign.; MTL vs. CON n.sign; ETL vs. CON p<0.05) with ETL patients exhibiting a much higher variance in this task.

One question to ask is whether the number of intransitivities was stable across time? Although each pair of options is seen once, prior choices involving one of the pairs might influence subsequent choices. In the extreme, we might think that these effects might occur differentially across groups. The MTL group, for example, might have less ability to benefit from past retrievals of an option, while the other groups may benefit from such retrievals. To examine this we examined how intrasitivities occurred across time. This analysis requires conceptualizing intransitivities not on triplet but trial level. To this end we computed how many times a trial was involved in a triplet that indicated intransitivity of choice. This was used as the dependent measure in a multilevel model with a random effect of individuals nested in groups and fixed effects of the centered trial number, centered quadratic term for the trial number and factors indicating groups as well as their interactions. Neither the trial number (t = – 0.41) nor the quadratic term (t = 0.91) had a significant effect on how many intransitivities a trial was involved in. The interactions were not significant either. An examination of the random effects reveals that there are sizeable individual differences in the effect of trial number on intransitivities. Though they were significant for some subjects we did not find a consistent pattern in these differences and as the multilevel regression indicates they are cancelled out on the aggregate level.

In a related analysis, we examined how long it took individuals to make the choices. We found no significant differences in mean reaction times between the groups (MTL = 1587 msec, ETL = 1408 msec, CON = 1413 msec, p = 0.12). This result held true even when we ran a multilevel regression accounting for individual differences. Overall we found that all subjects became faster in later trials. Trial number had a significant effect on reaction times in a multilevel regression (t = – 27.79). More importantly, however, the reaction times did not have an effect on the number of intransitivies (p = 0.81).

We also examined whether the intrasitivities were related to particular items in the set of 20 options. On trial level we regressed the number of times a trial was involved in an intransitivity on factors for each chocolate bar as well as group. Four bars appeared to significantly predict the number of intransitivities. Looking at how often each bar was chosen an ANOVA reveals significant groups differences (p < 0.001). Post-hoc test, however, do not reveal a clear pattern of most preferred options.

To make sure that the choices indicated preferences and not a lack of understanding the task or interest we checked how often each side was selected. There was only a marginal group effect in how often the left side was chosen (p = 0.094) but the MTL group chose the left side significantly less than 50 % (mean = 47.2 %, p < 0.001) while the two groups did not differ from 50% (mean left CON = 51 %, mean left ETL = 49.1 %).

**Discussion**

How do we account for the strikingly similar pattern that we observe in MTL patients with that observed in VMPFC patients? Obviously, they both may have independent functions in choice. Fellows (Fellows, 2006) has demonstrated that VMPFC lesioned patients show difference in external information search that could be attributed to diminished planning capacity. Whether that diminished planning capacity affects search of memory is an interesting topic of further research.

What is the status of the intransitivites that we observe?   Much research has used the existence of particular intransitive preferences as evidence of particular alternatives to value maximization (Tversky 1969…), but those demonstration have been criticized (Regenwetter).  In our work, we use instransitivities in a simper way, as evidence that a stable presence is less strong in those whose hippocampal regions have been impaired, that and the degree of that weakness is a function of the degree of damage.   This work parallels similar work implicating the VMPFC in value representation, but suggests a critical role for the hippomapus as the carrier of critical components needed to construct those values.

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1. Some trials timed out before subjects could indicate a clear preference. We checked all our calculations excluding the trials and triplets that may have been affected by this. All behavioral results even when these trials are excluded. [↑](#footnote-ref-1)