

How many times do you need to view content before it is registered in your memory

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ABSTRACT

This work investigates people's memory of viewed content and the number of exposures necessary for a memory of the content to be registered. Using electrodes implanted inside the brains of humans, we eavesdrop on the activity of neurons while the subject watches content. We show that after viewing the content twice the brain is likely to form a representation of the content and respond differently to a third presentation. This suggests that two viewings of marketing content (i.e., an ad or a commercial) are sufficient for the brain to register the concept presented.

INTRODUCTION

Advertisers and content creators who attempt to engage their audience often rely on repeated exposures to ensure memorability (Lee & Briley, 2005; Pieters et al., 1999). These content creators, intuitively, assume that showing an ad multiple times will increase the chance that its message will be registered in the viewer's memory. Once a memory is registered in memory, the chances that the concept it highlights will emerge spontaneously is higher (Mitchell, 2013). This spontaneous recall, in turn, is likely to probe a network of associations surrounding the memory and evoke various related prompts.

Marketing research has linked awareness with attention. Attention was, similarly, linked to interest. Interest is correlated with engagement. And engagement is a likely predictor of ultimate purchase (Cerf & Garcia-Garcia, 2017). Therefore, much of contemporary marketing relies on repeated exposures and increased engagements as a tool for promotion (see, for example, the classical *AIDA*: Attention, Interest, Desire, Action model; or, in the words of singer Ariana Grande: "I see it, I like it, I want it, I got it"; Priyanka, R., 2013).

But how often does one need to be exposed to a certain cue before they register it in their memory is not obvious. Evidently, some prompts require minimal exposure before they yield a permanent trace. For example, touching a stove once is sufficient to generate a long-lasting memory (Milner et al., 1998). Similarly, events that activate emotional circuitry in the brain (i.e., one's whereabouts and actions during the September 11, 2001 terror attack) are likely to be remembered vividly (LeDoux, 1994). Conversely, some exposures may leave little trace even after repeated exposures. It is not uncommon, for example, for people to meet strangers in social events, shake hands while both utter their name loudly, and realize moments later that those names are immediately lost in the void of both memories.

While the working of the human memory is subject to extensive research in neuroscience, the efforts are primarily directed at understanding the circuitry and systems driving the various processes involved in consolidation and recall (Kandel, 2009). Here, we use tools from neuroscience to empirically test the effects of exposure to content on memorability. Specifically, we ask how many exposures are necessary in order for the brain to, internally, generate a traceable record of the memory.

To ensure that the memory registration is not subjected to individual biases we test the memory registration directly within the brain rather than using subjective reporting. That is, we monitor the memory directly, at the neuronal level, using electrodes implanted in the brains of humans undergoing brain surgery. We expose the subjects to content and assess the number of repetitions needed to yield a stable neural response. This method ensures that even if the

person may not be *aware* that a memory is coded in their brain (i.e., if the exposure was peripheral or covert) we will be able to trace the activation of the consolidation circuitry.

This can inform marketing practitioners and communication experts who are interested in the very basic inception of an idea, the minimal number of exposures they need to ensure when planning a campaign. While this exposure does not guarantee memorability, liking, or even the ability to consciously note the memory activation, it acts as a lower boundary that the practitioners would want to note as beyond that cutoff the chances of awareness attention are higher.

METHODS

Subjects

Sixteen subjects participated in the study. Subjects were patients undergoing brain surgery who were implanted bilaterally with chronic intracerebral depth electrodes - primarily in the medial temporal lobe - to localize the epileptic focus for possible clinical resection (Figure 1a,c). Specifically, the main recording sites were: hippocampus, entorhinal cortex, amygdala, and parahippocampal gyrus. All subjects had normal or corrected-to-normal vision. Subjects could participate in the study multiple times while being monitored at the clinical setting. Overall, subjects participated in the study 2.5 ± 1.4 times (mean \pm standard-deviation) across three years of data collection.

Experimental procedure

Subjects viewed a sequence of 600 images. The sequence reflected 100 unique images appearing 6 times each, in random order. Across each of the 6 repetitions one presentation appeared in a blue distorted color that deviated from the expected image color. This presentation was considered an *oddball*. Oddball images could appear at any time during the sequence. The subjects were instructed to answer, after each image disappeared, whether it was an oddball or not. The images appeared on the screen for 1 second followed by up to 1 second response time. Prior to the image presentation, a fixation cross appeared on the screen for 1 second. Before the image sequence started, the subjects read the following instructions: "You will see a number of images. Some of the objects in the images are shown in an atypical color. You are asked to determine whether the color seems natural or not?"

Stimuli

All stimuli were presented at the center of the screen, occupying about half of the visual field. To generate the oddball images, two channels' color spectra (i.e., red/green) were filtered to enhance the third one (i.e., blue). Other than a color manipulation the oddball images were identical to the natural ones (Figure 1b).

Neural data acquisition

The exact electrode numbers and locations varied across subjects and were based exclusively on clinical criteria. Neuronal signals were recorded using 9–10 depth electrodes (Ad-Tech, Medical Instrument Corp., Racine, WI). Each electrode contained a bundle of nine Platinum-Iridium micro-electrodes protruding from its tip, eight high-impedance active recording channels, and one low-impedance reference electrode. Behavioral data were synchronized with the recorded spikes via 8-bit timestamps using the Cheetah software (Neuralynx Inc., Bozeman, MT).

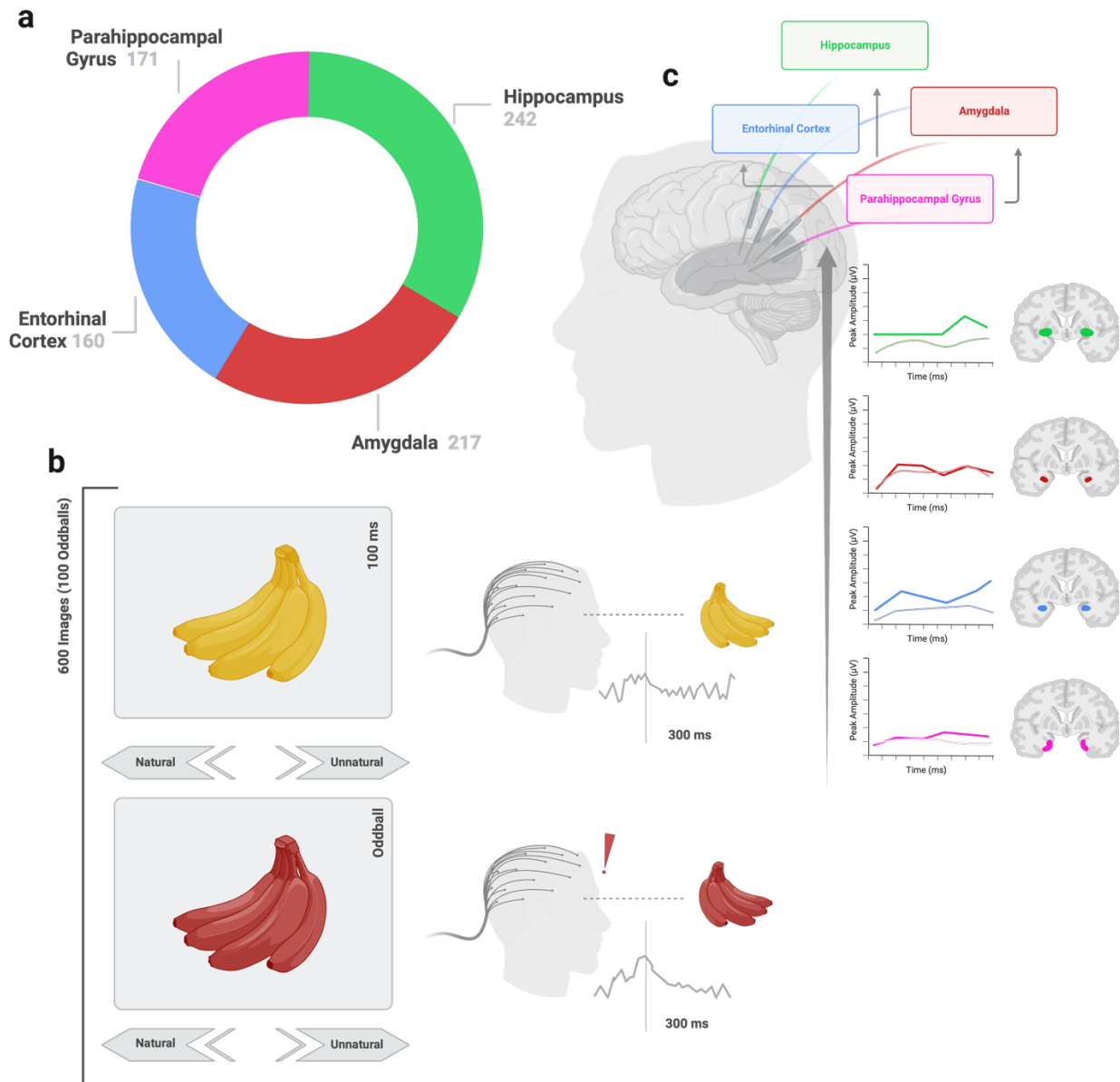


Figure 01. Illustration of the experiment design and unit breakdown. **A)** Distribution of all neurons within all regions, across all patients. **B)** Experimental Task; Patients viewed 100 oddball images embedded in a 600-image sequence, in random order, and were asked to classify each image as oddball/not. **C)** Depiction of the microwire electrode tip locations and Local Field Potentials (separated by right, thick line, and left hemisphere placements for various recording regions).

Spike detection

Differential neuronal signals (recording range $\pm 3,200\text{mV}$) were filtered (bandwidth 0.1–9,000Hz), amplified, and digitized (sampling rate 32,700Hz) using a 256-channel Atlas neurophysiology system (Neuralynx Inc., Bozeman, MT). After band-pass filtering the signals (bandwidth 300–3,000Hz), spikes were detected and pre-sorted. Manual verification and classification as an artifact, multi- or single- unit was based on spike shape, spike variance, inter-spike interval distribution per cluster, and the presence of a plausible refractory period. Only units that responded with an average firing rate greater than 1Hz during operand 1 and delay 1 phase for either format were included in the analyses.

Across all recording sessions from all subjects, a total of 3,152 units (379 single and 2,773 multi units) were identified.

RESULTS

To tell how many exposures are needed for a visual cue to be registered in memory we used the reversed *oddball* response. That is, if a stimulus was presented once followed by the oddball exposure, and the subject recognized that the second exposure was an oddball (both subjectively, and through an activation of a single-neuron coding oddball responses) we surmised that the first exposure already created a memory. If two exposures were necessary to yield the oddball response, then the brain effectively needed both exposures before it coded the stimulus as part of a

single pattern that was “broken” by the oddball. Effectively, the number of exposures *before* an oddball response is manifested was indicative of the amount of viewings needed in order to code an event as an isolated memory. Since we had 100 different cues which were randomly distributed across all exposure options (1-6 exposure options) we could identify the optimal number of presentations necessary.

To do so, we initially had to identify single neurons that coded the response to oddball presentations, irrespective of the stimulus type or exposure order. Pooling all trials, we identified population of single neurons that responded to the occurrence of oddball images more than non-oddball ones. Across all subjects, the response to oddball images was $11.9\% \pm 62.1\%$ higher than baseline (established by pooling all activity during the fixation periods). To verify that these changes indeed reflect responses to oddball activity we, additionally, analyzed the Local Field Potentials (LFP) from the electrodes of the units deemed responsive. Averaging the Event-Related Potentials (ERP) activity across all oddball trials and non-oddball trials and comparing those to equal length surrogate data selected randomly from the same channels we identified the expected P300 response (**Figure 1b**) that was previously illustrated in the oddball paradigm literature (Demiralp et al., 2001).

Next, using the responsive “oddball neurons”, we tested the effect of image order occurrence in three ways. First, we looked at the amplitude response to *any* oddball image (out of 100 images) within the experiment. That is, we asked whether, for each subject, the response to the first oddball image viewed is different than the second, ... up to 100-th. Across all regions we did not detect any significant change in amplitude or LFP peak latency within those trials. Second, we looked at the number of trials between consecutive oddball images as a predictor of change in amplitude/latency. The shortest gap between consecutive oddball images was 1 ($n=605$), and the longest was 79 ($n=1$). We used distances up to 6 given that those still yielded a sufficient number of trials for statistical power. No significant change in amplitude/latency was detected in those distances analysis. Third, we looked, within a specific stimulus category/object, for the difference in response to the oddball image based on its order of appearance (i.e., whether the first time a subject saw the oddball image was different than the second, ... 6th). We note that across regions, both the peak amplitude and the latency of the peak of the LFP response decreased (or remained same; but never increased) with exposures (**Figure 1c**). This aligns with prior studies in ERP.

With this hint that exposure times impact the coding, we focused on estimating the difference between the 1st and 6th oddball image presentation. The changes in firing rate were significantly different between the first and last trial. Narrowing the test to individual exposure presentation, we saw that after 3.99 exposure the likelihood of response to oddball image approaches 90%. That is, after 3-4 exposures to the visual cue the chances of an oddball activation is maximal. Put differently, if a person views a cue twice and then, on their third viewing, are seeing a manipulation of that cue, their brain will register the manipulation as an oddball. This suggests that the two exposures were sufficient for the brain to recognize the cue, code it as part of a pattern, and presumably generate a neural circuitry that processes it further as an isolated entity.

DISCUSSION

In an objective empirical work where humans were exposed to stimuli repeatedly following a presentation of an oddball stimuli that broke the visual pattern, we see that two viewings of the same stimuli are sufficient for the brain to generate a single unified memory for the cue. If the third exposure is an oddball, the brain would respond in a pattern indicative of a deviation from baseline firing rate. While the number of exposures varied across stimuli and subjects, the ability to identify a deviation from norms after two viewings approached 90% across all pooled trials.

Importantly, the test in this work does not rely on subjective reporting. The identification of the single neuron as “coding oddball” was done purely by correlating the actual oddball presentation and the neural response. Put differently, it is possible (and in fact, likely) that at times an oddball image was presented on the screen yet not recognized by the subject (i.e., they may have indicated that the image was natural) yet their neuronal activity increased in a way that indicates that the image was registered as odd.

Given that the exposure estimate is in fact distributed over a range, with three presentations being the peak (but not the ceiling), it is likely that additional exposures will increase the likelihood of memory/pattern locking. That is, marketing managers who want to increase their confidence that a cue is registered by exposing people to, say, four viewings of an ad, are likely to ensure the memory coding above the 90% chance we observed. We could not investigate the exposure profile given the small number of trial options (to test 6 exposure types we needed 600 iterations which took about 30 minutes per subject; additional exposures would have increased the study beyond the accepted duration for patient testing in the clinical setting). Therefore, we cannot tell whether additional exposures would provide significantly increased benefit or only marginal strengthening of the memory. Intuitively, one assumes that more exposures are probably better irrespective of their incremental value, yet the exact utility remains unknown. Further, our study did not test the *duration* of the memory coding. It is plausible that after, say, weeks of no-exposure to the cues, its residual memory would be diminished, and an additional exposure would be required to re-ignite the exposure process.

That said, marketing managers who are interested in ensuring that a momentary message (i.e., a current campaign) would drive immediate awareness and potential recognition can now use this empirical evidence for the fact that two exposures are already yielding a memory - irrespective of the gap between presentations, or cue content – as a guideline for their marketing planning. This, For example, managers who generate an online campaign that is meant to drive awareness, can indicate that if an ad was already seen by a viewer twice, there is no need to expose them to it again (thus, allocating resources to exposing other viewers to the ad).

Limitations

Notable limitations of the work stem from the choice of stimuli, presentations modality, and interpretation.

Specifically, we elected to use solely *visual* stimuli in our study. While those account for the majority of current advertising content (Krishna et al., 2016) it is important to remember that other modalities (i.e., auditory cues or olfactory ones) may be registered in different ways by different neural circuits. Therefore, other modalities may require more/less exposure. Further, it is possible that a combination of, say, visual cues and auditory one may change the process (i.e., speed it up).

Another limitation of our work emerges from the fact that we focused on *whole brain* analyses rather than regional evaluation. Prior works investigating oddball responses have suggested regional and hemispheric differences in the oddball neural coding (Başar-Eroglu et al., 2001). It is plausible that our averaging across the entire brain masked a more nuanced effect (i.e., responses in one site code stimuli after two exposures, whereas another site requires more exposures).

A third limitation is manifested in the translation of the work from the realm of neuroscience to that of marketing. While we could show that the brain requires two exposures to register a pattern at 90% accuracy, it is not obvious that the *person* is actually aware of the pattern consciously. It is possible that neurons in the brain register the oddball cue subconsciously in a way that is not manifested behaviorally. While it is known that covert processes impact behavior (Cerf et al., 2015; Freiberg & Cerf, 2022; Milosavljevic & Cerf, 2008), it is noteworthy that marketing managers are likely to care more about conscious processes (i.e., ones that can be identified also in a survey or a subjective reporting). Ultimately, the choice to act in response to a cue (i.e., make a purchase) is probably mostly conscious. Therefore, future work should look not only at the neural output but also the manifested behavioral response.

Finally, it has not escaped our notice that the stimuli we used were not typical marketing messages, lacking a persuasive component. These images were ideal for an objective test but may not reflect the traditional marketing communication. We speculate that our results may therefore act as an upper bound to the amount of exposure needed. A persuasive message is likely to be more memorable and therefore registered earlier. If the presented content is tailored to the individual's personality, interest, and situation, the effectiveness of the message should be even higher (Matz et al., 2023). The combination of persuasive content, with targeting that is geared not just towards a "segment" but towards a specific brain (or "brain state", corresponding to a single person, at a specific situation, mood, or mental state) could yield an even more effective memory registration (Matz et al., 2022).

As neural implants and brain-machine interfaces (Wang and Cerf, 2022) are becoming more accepted, and as some tech giants are actively working towards integration of devices into people's heads – hoping to replace the current mobile/web interfaces (Agnihotri and Bhattacharya, 2023) - it is possible that studies like this one will be more common. Marketing practitioners will need to become more fluent in the workings of neural circuitries as marketing messaging directed towards internal processing will become viable (i.e., marketing directly to a person's sleep/dream; Cerf, 2023). In such future, the need to understand how/when content is registered in the brain will become instrumental.

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