Memory Strategically Encodes Externally Unavailable Information

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Abstract

In the present study, we test the theory that humans selectively encode incoming sensory information on an as-necessary basis, when the information would not be accessible otherwise, in order to compensate for cognitive limitations on the quantity of new information that they can encode. We investigate whether external informational sources—much like high-level knowledge obtained from previous experiences—can spare learners from having to encode all new information in fine-grained detail. If this is true, we would expect to observe differences between the way human learners encode new information that they know to be easily available through external informational resources (e.g., names of actors in a movie, the date of a historical event) and those that they know are not (e.g., names of new acquaintances, the date of a wedding anniversary). Specifically, we would expect learners to encode far less detail for information that is available through known external informational resources than for information that is not. We present evidence from a study run on Amazon Mechanical Turk that human memory preferentially encodes information that is not expected to be available from external informational resources.

Keywords: Memory; learning; education; human experimentation.

Potential Effects of External Memory Devices on Human Cognition

External informational resources (e.g., books, pictures, Wikipedia, notes) have the potential to act as *external memory devices* for users by enabling them access to knowledge that they need not have encoded and stored in their own memory banks. Smart phones, one of the most common and widely used personal information-providing devices to date, are a prime example of technology that could act as an external memory device for users. Smart phones give users quick access to both universal types of knowledge (e.g., answers to common and uncommon questions about the world), as well as more personal facts (e.g., names and phone numbers of contacts, items on a personal grocery list). Previous research has established that there are capacity limitations on how much sensory information learners can encode into memory as they interact in the world (e.g., Alvarez & Franconeri, 2007; Huang, Treisman & Pashler, 2007; Lavie, 2005; Plude, Enns & Brodeur, 1994; Saalmann, Pigarev & Vidyasagar, 2007). Thus, preferentially encoding into memory only information that is inaccessible through external means would be advantageous because it would reserve the limited processing capacities in humans for material that cannot be obtained elsewhere. In this study, we test whether human learners reserve their limited cognitive resources for information that is not externally retrievable.

Previous work has established several cases in which learners are capable of employing sensible strategies in selecting what information to encode into memory from all available sensory input that they attend (e.g., Hemmer & Steyvers, 2009; Henkel, 2014; Sparrow, Liu & Wegner, 2011). For example, Henkel (2014) analyzed the effect that picture taking has on memory. This study found that taking pictures substantially reduces one's ability to recall scene details. Another study conducted by Sparrow, Liu and Wegner (2011) looked at whether the same phenomenon applied to written knowledge. In this study, Sparrow et al. tested whether individuals would remember information that they believed would be inaccessible later by measuring differences in recall after manipulating participants' beliefs about the storage state of information. Subjects were asked to type 40 facts into a computer program that they were either told would *save* or *erase* the facts, depending upon the condition to which the subject was assigned. After this typing task was complete, subjects were then asked to type out as many of the facts as they could remember. Those who believed that the computer had erased the facts that they had previously typed into the program performed better on the recall task.

Our study aims to build on these previous findings by testing the hypothesis that individuals continually track what information they expect to be available in the future, even in the absence of any overt cue, and that they preferentially allocate memory resources to information that they expect to be unavailable through other means. This would test whether the strategic processes studied by Henkel (2014) and Sparrow et al. (2011) operate automatically and continuously in memory to track the likely future availability of information as it is received. We predict that learners will employ an efficient encoding strategy even in the absence of an explicit reference source (e.g., a photo, notes), but also reference sources people know to exist in the world (e.g., Wikipedia, IMDB). Although researchers have speculated about this possibility (e.g., Sparrow et al., 2011), no one has previously published empirical evidence in support of this hypothesis.

We hypothesized that individuals track what information they expect to have access to later on (e.g., via the internet), and that information that they know is likely to be accessible through some external source will be deprioritized

Table 1: Examples of web-savviness questions.

Question	Answer	Difficulty
Which state in the United States was the last to allow right turns on red?	Maryland	Easy
What's the title of the most popular video by Rosanna Pansino on YouTube?	How to Make a Frozen Princess Cake	Medium
What date did Wikimedia Foundation Inc. register wikipedia.org?	January 13, 2001	Hard

for encoding into memory than information that they know is unlikely to be available elsewhere. To test our hypothesis, we conducted a computer-based behavioral study via Amazon Mechanical Turk that was designed to examine whether people preferentially encode information that is not available through other external informational resources. We also tested whether this effect was moderated by familiarity and skill with looking up information online. We hypothesized that if memory is in fact strategically allocated based on expectations about future access to information, people who are more familiar and skilled with looking up information online will show a greater preference for encoding the kind of facts that cannot easily be looked up.

Methods

We tested subjects' memory retention of facts from two categories—those that could easily be looked up online, and those that could not—using a within-subject design. If subjects strategically encode information with respect to their expectations about the future availability of that information, we expect that they will more accurately remember the kinds of facts that cannot be looked up online than those that can. Additionally, we measured subjects' familiarity and skill with looking up information online. We expect that, if an effect of the availability of information online exists, it should be moderated by how familiar and skilled subjects are at retrieving information online. This is because a subject must be able to recognize what kinds of information are easily retrievable online and what kinds are not in order to generate different expectations for these two sets of fact types.

Subjects

One hundred and fifty subjects were recruited using Amazon Mechanical Turk. Subjects were required to be at least 18 years old and have IP addresses in the United States. We paid each participant a rate equivalent to 10 dollars an hour (the same rate as lab-based studies), with the opportunity to receive additional compensation as a bonus for good task performance.

Task and Materials

The two-part experiment was conducted on Amazon Mechanical Turk. Subjects were instructed to complete the task alone in a quiet environment, and to turn off any music or other devices in order to minimize distractions. Subjects had one hour to complete the task. All subjects completed both parts of the experiment described below in immediate succession.

Part 1: Web-savviness assessment Part 1 measured subjects' "web savviness" (i.e., how familiar subjects were with looking up different types of information online). This section contained a list of 12 questions about information that could be looked up online, but that varied in difficulty (see Table 1). The answers to easier questions could be searched for quickly and directly via Google (e.g., "Who is the state senator for the 28th district in New York state?"), while the answers to harder questions required multiple searches via specialized informational platforms (e.g., "What was the high and low temperature in Rochester, NY on June 9th, 2014?"). Part 1 instructed subjects to use the internet to locate as many correct responses as possible in exchange for additional bonus compensation for each correct response. The proportion of correct responses in Part 1 provided an indicator of their skill level and familiarity with looking up information online.

Part 2: Memory test Part 2 measured subjects' memory for facts of two distinct types: those than can be easily accessed on the internet (*lookupable*, e.g., the value of the mathematical constant *e*) and those that cannot (*nonlookupable*, e.g., a locker code). Part 2 asked subjects to read 20 presented facts and memorize as many of them as possible, without the aid of notes. Prior to the start of Part 2, participants were presented with a practice fact and a follow-up question to ensure that they fully understood the procedure. After successful completion of the practice question, each subject saw 10 randomly selected facts (from a larger set of 99 facts[1]) of each type, lookupable and nonlookupable, interspersed together with no overt indication of their fact type in a randomized order. (See Table 2.) Each fact appeared on the screen for 10 seconds.

The 99 facts in the lookupable condition were designed to be sufficiently obscure in order to minimize the likelihood that any of the subjects would have known them prior to the experiment. As an additional check, subjects were asked after the experiment if they knew any of the facts in advance of the study, and these trials were omitted from further analysis (0.09% of responses). For each fact in the lookupable condition, a nonlookupable fact was constructed to be similar in terms of form, structure, and complexity. (See Table 2 for example facts.) As a cover explanation for the nonlookupable facts, subjects were told that the facts were compiled by an elementary school class in Rochester, NY. Thus, the nonlookupable facts detailed information of a similar type to

[1]The original full set of facts contained 100 of each fact type, but one was cut before the experiment was run due to a typo.

Table 2: Examples of memory test facts.

*Lookupable facts**
The mathematical constant e is equal to 2.71828.
The first major motion picture to star an African-American woman was ZouZou.
The world record for the most number of children a father has ever had is 867.
Charlotte Lee holds the record for the largest collection of rubber ducks in the world.
*Nonlookupable facts**
The code for the playground equipment locker is 6 - 0 - 4 - 6 - 8 - 4.
The first community theater play to star a student from the elementary school was Matilda.
The total number of kids enrolled in the elementary school right now is 590.
Tamara Greene has the largest sticker collection of anyone in the elementary school.

* Underlined words were replaced by a blank space for the fill-in-the-blank memory test following the fact presentation in the experiment. See also Figure 1 for an example memory test screen.

the lookupable facts, but pertaining to people on the smaller, local scale of the elementary school (thus, giving the impression that they were not the sort of facts one could easily look up online).

A 20-question recall test followed the fact presentation. Participants were asked to fill in the blanks for 20 fact statements (10 lookupable and 10 nonlookupable). (For an example of the fill-in-the-blank memory test screen, see Figure 1.) Subjects were asked not to use any aids in answering these questions, including the internet, other people, or any other information resources they might have available in their homes. As a check to ensure that they abided by these instructions and did not look answers up online, one of the lookupable fill-in-the-blank facts was replaced by another lookupable fact from the larger 99-fact set that they were not shown during the fact-presentation phase. Since the lookupable facts were obscure, a correct answer on this swapped-out fill-in-the-blank fact (which the subject had not seen during the testing phase) would likely indicate use of the internet. Thus, subjects who answered this question correctly could be omitted from further analysis. In our 150-person sample, none were omitted for this reason because all subjects answered this question incorrectly.

At the conclusion of the study, subjects were asked to report any facts they encountered throughout the experiment that they knew in advance of the experiment. Facts that subjects reported knowing in advance were omitted from the memory task analysis (0.09% of responses). Additionally, 3 subjects reported knowing facts in advance of the experiment that they were not shown during the experiment, suggesting that they had either completed the study previously with different Mechanical Turk accounts[2] or that they received information about the task from other subjects, either due to being physically present while another subject completed the task or via online conversations. These subjects were omitted from further analysis.

[2]Amazon Mechanical Turk accounts that had completed the task could not complete the task again.

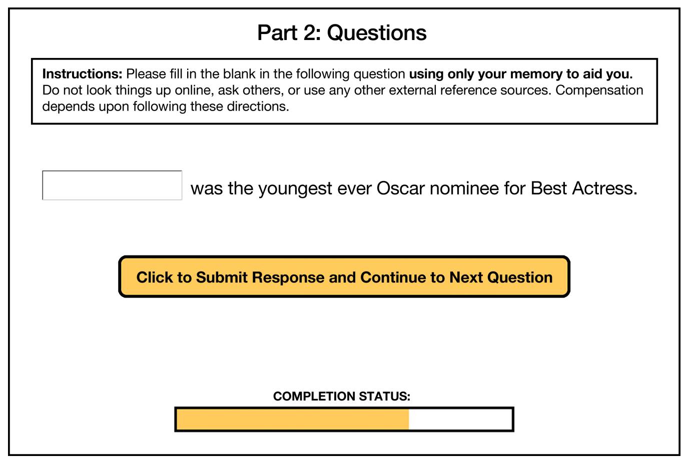

Figure 1: Example of fill-in-the-blank memory test screen used to assess accuracy of memory for 10 lookupable and 10 nonlookupable facts per subject. The above is an example of a lookupable fact. Subjects responded by typing their answer into a textbox and clicking a button to submit their response.

Analysis

We first compared the mean accuracy of subjects' performance on the memory test by fact type (lookupable and nonlookupable) using a Wilcoxon signed-rank test paired by subject. To test our hypothesis controlling for subject and item effects, we used a mixed-effect regression predicting accuracy from fact type, web savviness, and their interaction. We also included random intercepts by item, along with slopes and intercepts for subject (Gelman & Hill, 2007). This analysis ensured that any differences we observed in group means by fact type were not driven by differences in individual items

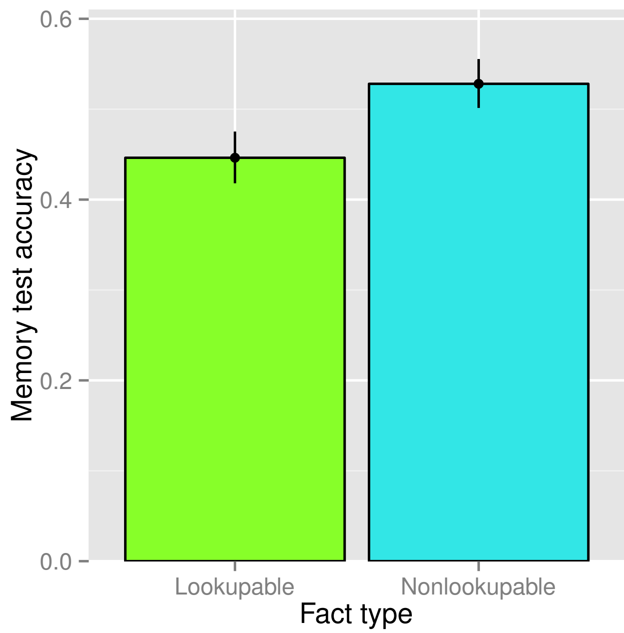

Figure 2: Memory test accuracy by fact type (lookupable versus nonlookupable). Subjects more accurately remembered significantly more nonlookupable facts than lookupable facts (52.8% versus 44.6%, V=3297.5, $p<$ 0.0002), consistent with the hypothesis that subjects would preferentially encode information that they believed to be less available in the future. The error bars depict 95% confidence intervals. Note that the memory test involved free-recall responses, and thus chance performance is likely to be very low (not 50%) since free recall of arbitrary facts is difficult.

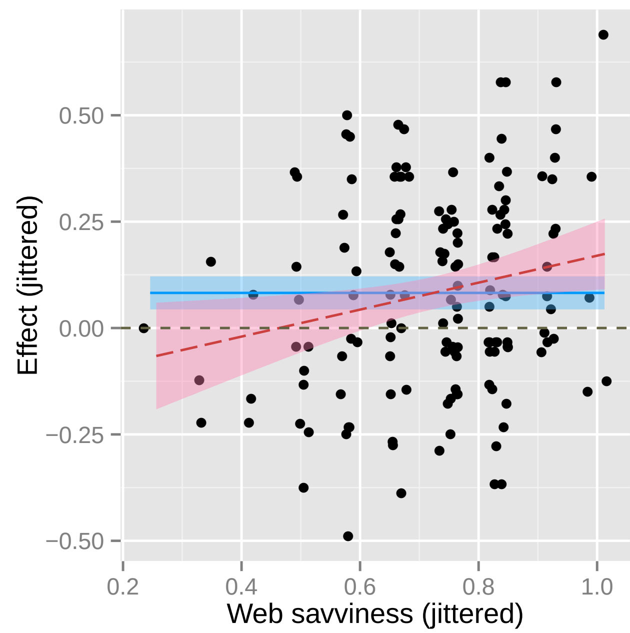

Figure 3: Effect size—degree of improved recall for nonlookupable facts over lookupable ones—by score on web-savviness assessment. The grey dotted line shows chance performance. The solid blue line shows mean improved performance for nonlookupable facts over lookupable facts (the main effect of fact type for the experiment). The dashed red line shows the interaction with web savviness. More web-savvy subjects show a greater difference in accuracy for their memory of nonlookupable facts over lookupable facts. Transparent areas indicate 95% confidence intervals.

or subjects.

Results

Accuracy on the memory test by fact type is depicted in Figure 2. Subjects more accurately remembered the nonlookupable facts (52.8%) than the lookupable facts (44.6%), consistent with the hypothesis that subjects would preferentially encode information that they believed to be less available in the future. A Wilcoxon signed-rank test (with continuity correction) paired by subject found this difference to be highly significant (V=3297.5, $p<$ 0.0002). It is important to note that the memory test here involved free recall, and that chance performance on free recall of arbitrary facts is likely to be well below both fact-type means (i.e., well below 50%), meaning subjects performed above chance for both fact types.

The results of the mixed-effect regression are in Table 3. The mixed-effect regression revealed a main effect of fact type (β=0.085, t=4.759, $p<$0.0001), such that subjects were more accurate on the memory test for nonlookupable facts. The regression also revealed a main effect of web savviness (β=0.042, t=2.617, $p<$ 0.01), such that those who demonstrated greater skill with looking facts up online also performed better on the memory test overall. The regression also revealed a marginally significant interaction between fact type and web savviness (β=0.030, t=1.653, $p<$0.10), suggesting that those who were more web savvy showed a stronger tendency to better remember nonlookupable facts. This effect is also apparent in Figure 3, which shows both the group mean effect along the solid blue line at 8.2% (mean accuracy on nonlookupable facts minus that for lookupable facts) and the interaction along the red dashed line. The effect size increases for more web savvy subjects, consistent with our hypothesis.

Conclusion and Discussion

The results suggest that human learners strategically encode into memory information that they expect to be unavailable in the future. Further, our data suggest that learners track their expectations about what information they expect to be available automatically and continuously, even in the absence of any explicit cue. This finding characterizes the memory system as resource-rational, automatically seeking to minimize

Table 3: Mixed-effect regression evaluating effects of fact type, web savviness, and their interaction.

	Coeff.	Error	df	*t*	*p*	
(Intercept)	0.449	0.024	163.60	18.548	<2e-16	***
Nonlookupable	0.085	0.018	145.27	4.759	<4e-6	***
WebSavviness (scaled)	0.042	0.016	145.81	2.617	<0.01	**
Nonlookupable : WebSavviness	0.030	0.018	146.21	1.653	<0.10	.

unnecessarily stored information.

More broadly, our results demonstrate that human learners possess some metacognitive awareness of their ability to look things up online. Further, our results show that those who are better at it also offload more lookupables from memory. Given the increased availability of information on the internet, these results have interesting implications for how new technologies might be expected to influence fundamental aspects of our basic cognitive processes. Specifically, they suggest that human memory makes efficient use of these new technologies by deprioritizing storing information that can be easily accessed on an as-needed basis elsewhere. This finding is in line with other work that demonstrates that memory efficiently favors encoding information that is not readily accessible via another external source such as a photo (e.g., Henkel, 2014) or a partner (e.g., Engestrom, Brown, Engestrom, & Koistinen, 1990; Harris, 1978; Wegner, Erber, & Raymond, 1991). However, this idea stands in stark opposition to some theories that posit that the availability of information on the internet should have a negative effect on the functionality of human memory because people may "fail to distinguish between information stored online and information stored in their own minds" (Ward, 2013). These findings could have major implications for future studies of learning, memory, and attention, in addition to obvious applications in the domains of clinical research (e.g., more effectively treating learning disorders, ADHD) and educational policies (e.g., more effective curriculum in schools).

The effect observed here likely reflects a strategy for reducing cognitive load. Memory tracks the availability of information it encounters and deprioritizes encoding material that is available elsewhere. This strategy is very similar to a now well established efficient encoding strategy in memory that involves prior knowledge. Just as memory may utilize prior knowledge to reduce cognitive load when encoding new information (e.g., Bartlett, 1982; Bower, Black, & Turner, 1979; Hemmer & Steyvers, 2009; Schank & Abelson, 1977), memory may utilize knowledge of informational accessibility similarly.

Further work will be needed to ascertain the potential importance of context on this effect. In this experiment, subjects completed the web-savviness assessment in advance of being asked to memorize facts for testing. It is possible that this framing of the task put them in a state of mind that cued them into tracking what facts were lookupable versus which were not. Alternatively, it is also possible that human learners

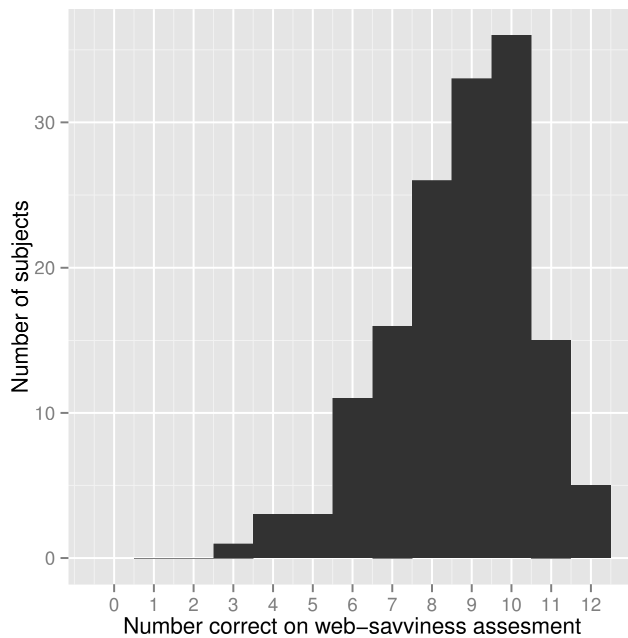

Figure 4: Histogram of web-savviness assessment scores across all study subjects. The skew to the right indicates that subjects may have been relatively web savvy, likely due to the fact that they were recruited on Amazon Mechanical Turk, an interface which attracts a relatively web-savvy group of users.

track this fact about the world regardless of particular context. Follow-up work that counterbalances the order of the memory test and the web-savviness assessment is in progress.

The fact that the interaction between fact type and web savviness attained only marginal significance in the mixed-effect regression will require further investigation. One limiting factor on this analysis was that the population of subjects were all relatively web savvy, likely due to the fact that they were recruited on Amazon Mechanical Turk, an interface that only attracts relatively web-savvy users (see Figure 4). This is evidenced by the fact that the median score on the 12-question web-savviness assessment was a 10. It could be the case that the interaction lacked the power required to reach significance because of this limiting factor.

Though the size of effect observed here was modest, it was highly significant. It should be noted that further work will be needed to understand the true effect size. In our experiment, the facts were matched as closely as possible for structure and complexity; however, they differed, by necessity of the design, in terms of the scale on which they applied. The lookupable facts referred to things of broad significance in the world (e.g., world records, events of historic significance) while the nonlookupable facts were only of significance on a smaller scale that was highly removed from the subjects we tested (e.g., personal facts and records at a local elementary school). A subject might, for example, want to recall an interesting obscure fact about a world record at a cocktail party. In contrast, it is unlikely that a subject would want to recall a similar, even more obscure fact about a record at an elementary school to which they have no personal connection. The lookupable facts are thus likely to induce more curiosity in subjects, which has been demonstrated to lead to stronger encoding into memory (Kang et al., 2009). This effect is thus likely working *against* the one we sought to study—the effect of expectations of future inaccessibility of the information on memory—because it likely made the lookupable facts more memorable. Thus, the true effect size of informational inaccessibility on memory may actually be greater than what we have reported here.

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