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Symbolism itself does not improve memory for elements on the periodic table

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Recent work demonstrates that symbols (e.g., \$) are reliably better remembered than their word counterparts (e.g., 'dollar'). It remains an open question whether the memory benefit observed for symbols is due to their unique visual form, or because they offer a symbolic representation of to-be-remembered information. Here, we assessed memory for symbols on the periodic table of elements, which could be presented in symbol format (e.g., H) or word format (e.g., Hydrogen), and compared both to memory for meaningless letters (e.g., J). These stimuli were selected because they all share the same visual features and the former two share the same meaning. Memory was compared across individuals with and without a background in chemistry. In non-experts, memory was highest for words relative to symbols and meaningless letters. In experts (students who had passed an introductory chemistry course), however, memory for words and symbols was equivalent, with both higher than for meaningless letters. Results suggest that prior knowledge of what a symbol means is necessary to gain a memory benefit over semantically-void information, but is not enough to boost memory relative to words. We suggest that using a concrete visual symbol to represent an abstract concept is not enough to confer a memory advantage relative to words; a meaningful and visually distinctive symbol may be necessary.

Keywords Memory, Dual-coding, Symbolism, Symbolic cognition, Periodic table of elements

Symbols are important and pervasive in everyday life. Recent work has started to home in on symbols as an important category of stimuli worth exploring due to their visual distinctiveness, efficient conveyance of meaning, and socio-cultural importance, not to mention their impact on human cognition. For instance, symbols (e.g., ☠) are often more memorable than their word-based counterparts[1] (e.g., 'poison')—the *symbol superiority effect*. Similarly, memory for information presented as a logo is typically better remembered than when presented in word format; for example, the Toronto Blue Jays baseball team sports logo is more memorable than 'Toronto Blue Jays' presented as text[2]. In our prior work on the subject, the 'symbol superiority effect' was reliable when participant memory was assessed using free recall, old/new recognition, and when the word comparators instead referred to concrete objects (common kitchen vegetables). Importantly, memory for symbols could be predicted by a deep neural network (ResMem)[3], suggesting symbols have inherently memorable features. While our stimuli in these studies referred to the same concepts (e.g., 'dollar' and \$), and thus had highly similar semantic attributes, words and symbols still differed in other aspects such as their visual appearance and reliance on symbolism to evoke meaning. The goal of the current study was to disentangle these features that distinguish symbols from words to define the critical factors leading to symbol superiority in memory.

Accounts of the symbol superiority effect

While there has been relatively little research on the cognitive and neural processing of symbols to-date, there is a rich literature investigating a similar stimulus type—namely, pictures[4–11]. Stretching back to the beginnings of modern psychology[12], there has been extensive work pointing to images as being especially memorable stimuli. This is captured in the well-known *picture superiority effect* in which pictures are found to be better remembered than words[9].

But how similar are pictures and symbols? On the one hand, they are qualitatively distinct as the former is often used to represent concrete objects (e.g., an apple) whereas the latter is typically reserved for more abstract concepts (e.g., love). In addition, symbols are often integrated within written language (e.g., punctuation and mathematical symbols like !@ + #\$%?), unlike pictures. On the other hand, recent work has shown that symbols

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and pictures can be recalled at almost identical rates[1], pointing to the possibility that these two stimulus types are coded similarly in memory. Symbols, therefore, may represent a special class of image-like stimuli that are more pervasive and flexible in their contextual use (such as standalone or integrated with written text). Critically, if symbols are indeed processed like pictures in memory, then one can apply the rich literature on picture superiority when hypothesizing about the cognitive mechanisms underlying memory for symbols.

One account of the 'symbol superiority effect'—based on Paivio's dual-coding theory[9], previously used to explain picture superiority—posits that the visual attributes of symbols confer a benefit by adding a secondary, 'image' code to memory[1]. This account contends that, when a symbol is observed it automatically produces an image code in memory while oftentimes also eliciting a verbal label from the observer (e.g., upon viewing '☮', the observer gains an image code in memory and also thinks "peace"). At the same time, this account suggests that the elicitation of dual codes is rarer in the reverse case: Upon reading the word 'peace', an observer is less likely to spontaneously create an image of the peace symbol in their mind's eye. In brief, a dual-coding account posits that symbols often evoke two representations in memory (image and verbal) whereas words are likely to only elicit a single (verbal) representation. As a consequence, to recall a symbol one can output the name of the symbol directly (e.g., 'dollar') or first think of the image of the symbol (e.g., $), which then more easily cues the target word to recall. Put simply, dual-coding provides two possible avenues to recall a target, and as such, enhances the probability of successful retrieval[11].

Another possible explanation for the symbol superiority effect is that symbols are memorable because of their relative conceptual[13] and/or physical[6] distinctiveness—factors thought to underlie memory advantages for pictures as well[14–16]. Applied to the case of symbols, a similar logic can be deduced: There are very few symbols that have overlapping meanings or high visual similarity, especially when compared to words. For instance, consider that many words have relatively poor conceptual distinctiveness due to the existence of synonyms. The word 'play', in the context of starting a piece of digital media, has many substitutes like 'commence', 'start', or 'begin.' On top of that, words can also have multiple interpretations ('play' could instead refer to an entirely different concept, like a theatrical performance). The symbol for 'play' (▷), on the other hand, is not only restricted to a single interpretation, but there is also no substitute symbol that can be used to communicate the same idea. Yet also now consider that words in the English language (e.g., 'biohazard') are only ever comprised of the same 26 letters in the alphabet and thus contain shared visual features, whereas the physical form of symbols can vary freely (e.g., ☣). As a consequence, the distinctiveness of symbols compared to words along conceptual and/or physical dimensions could lead better memory through eased retrieval processes enabled by constrained episodic search, and/or a lack of competition from partially overlapping information in memory[17].

The potential role of symbolism

While accounts based in dual-coding or conceptual/physical distinctiveness have considered the visual and semantic nature of symbols, they share a common limitation in that the effect of 'symbolism' itself was always included as a third variable. In other words, it could be the case that it is not the *image-like* nature nor the *distinctiveness* of symbols that confers them an advantage in memory, but rather the fact that they are symbolic to begin with.

American philosopher and father of semiotics, Charles Peirce, defined signs (what we refer to here simply as 'symbols') as "something which stands to somebody for something in some respect or capacity"[18]. In other words, symbolism can be operationally defined as the use of one thing to refer to another. This is one of the key aspects differentiating symbols and pictures: An image of a dog refers only to that dog and its exact physical form, whereas the symbol for poison (☠) refers more generally to *all* poisons. In essence, there is a level of abstraction required on-part of the observer when interpreting a symbol, as it is used to convey some idea beyond its exact physical form. It is possible, therefore, that the act of having to interpret the meaning of a symbol in a given context drives memory improvements via some yet-to-be-realized mechanism. Therefore, an important question remains: Are symbols highly memorable because of their visual and/or conceptual attributes, or because they are *symbolic* in nature and require abstraction?

Current study

To address this question empirically, we designed a study to hold semantics constant between word and symbol stimuli (as had been done before in[1,2], e.g., $ vs 'dollar'), while newly, also maintaining visual similarity. Therefore, when comparing memory for words and symbols in our current paradigm, the only factor left to differ between conditions was whether a concept was represented in symbol or word format (i.e., the effect of 'symbolism'). To enable this level of experimental control, a special set of stimuli was used: Symbols and words referring to elements on the periodic table (e.g., 'K' vs. 'Potassium'). Put another way, symbols from the periodic table should be equivalent in every way to their word counterparts, except in so far as they refer to chemical elements *symbolically,* rather than directly with phonetics (as words do). Therefore, comparing memory for elemental symbols from the periodic table relative to their word counterparts allows one to isolate the effect of symbolism on memory performance.

While symbols from the periodic table do indeed use characters from the English alphabet, they only serve as symbols when an observer is familiar with their meaning. In other words, when the letter 'H' is presented to those unfamiliar with chemistry, it is interpreted as a mostly meaningless grapheme (i.e., a letter), but when presented to someone familiar with chemistry, the character can now serve as a symbol referring to the element 'Hydrogen'. We examined this shift from letter to symbol in our study by comparing memory performance in a group of participants unfamiliar with chemistry ('non-experts') to those with high familiarity ('experts'). Experts were undergraduates who had successfully completed one or more first-year chemistry courses offered at the university (requiring detailed knowledge of the periodic table), while non-experts were undergraduates that had not completed any of those courses.

To ensure that viewing letters on a screen was not simply an inherently poor way to encode content for a later memory test, a 'meaningless letters' control condition was also introduced. Here participants were tested on their memory for letters and letter combinations that do *not* appear as symbols on the periodic table of elements (e.g., 'J', 'Kp'). In so doing, the visual forms of these three conditions ('symbols', 'words', and 'letters') was held constant (since they all use the same character set). At the same time, semantics were either entirely void for all participants in the case of the meaningless 'letters' condition, available to all participants in the case of the 'words' condition, or selectively available to participants in the 'symbols' condition depending on their level of expertise with the periodic table.

We expected to find a main effect of condition such that memory for words, symbols, and letters would differ overall, but no main effect of expertise (as there should be no inherent memory advantage for those familiar with chemistry, except for in the case of remembering symbols from the periodic table). We did expect, however, that these two main effects would be qualified by an interaction. When breaking down the interaction, the critical comparison of interest was whether the differing memory performance between groups was driven by higher memory for symbols relative to words in experts compared to non-experts. We predicted that if symbolism itself is indeed a critical factor conferring some special benefit to memory, then expert participants should experience memory improvements for symbols relative to words (and meaningless letters). On the other hand, if an image code or visual/conceptual distinctiveness is required for the symbols to elicit better memory than words, then memory for symbols and words should not differ in the expert group, as both stimulus types are matched on these features. In sum, if the influence of symbolism itself is enough to drive memory improvements for symbols relative to words, experts should exhibit the typical symbol superiority effect while non-experts should not. If symbolism does *not* underlie the symbol superiority effect, and instead the effect relies on picture-like visual/conceptual features, then neither group should demonstrate a benefit to memory for symbols relative to words.

Method

Participants

An a priori power analysis was conducted using G*Power software (v. 3.1.9.7)[19], targeting the smallest effect of interest in this study: A between-subjects comparison of memory accuracy for symbols and words, as found in a previous, similar experiment[1] ($d = 0.47$, $\alpha = .05$, power = 80%, two-tailed). This analysis indicated a minimum target sample size of $n = 73$ per group. Although the minimum target sample size was set at $n = 73$, errors in the group assignment process resulted in initially unequal sample sizes. To remedy this, the sample size in each group was raised until all groups contained roughly equal numbers of participants. In the end, a total of 1153 University of Waterloo undergraduate students took part in the study during a single online session in exchange for course credit.

Participants self-selected to participate in the study and had self-reported normal or corrected-to-normal vision, as well as having learned English before the age of 9. To increase our confidence in the validity of data obtained running an online study, we asked participants at the end of the study whether their participation occurred under 'ideal' conditions or not. Ideal conditions were defined as the participant was paying attention, understood the tasks, and were not distracted. Participants were assured that their credit would be granted no matter their response. In addition, participants indicated on a screening questionnaire whether they had successfully passed at least one introduction to chemistry course at the University of Waterloo (CHEM 120: General Chemistry 1, or CHEM 121: Physical and Chemical Properties of Matter). Critically, a high level of knowledge of the periodic table of elements is assumed and tested in these courses, making graduates of these courses highly familiar with symbols on the periodic table. Participants who had completed one of these courses were considered 'Experts', while those that had not were considered 'Non-Experts.' Participants were randomly assigned to one of our three experiment conditions. They were asked to encode words, symbols, or meaningless letters (the latter is hereon referred to simply as the 'Letters' condition), and their memory was later assessed.

From the initial raw data set, *R* statistical software was used to remove participants' data in sequential steps if they (1) had self-reported non-ideal conditions (e.g., distractions) while completing the experiment ($n = 211$), (2) took less than 5 min to complete the study ($n = 0$), (3) took more than 40 min to complete the study ($n = 38$), (4) were ± 3 *SD* away from the mean of remaining participants for study duration ($n = 15$), (5) had duplicate attempts at the experiment ($n = 9$), or (6) were missing more than 10 recognition test responses in their datafiles (a data collection error often resultant from rushing through the memory test; $n = 41$). After these exclusions, the sample consisted of 839 participants. Then, participants' data were excluded if their memory performance was ± 3 *SD*s away from the mean in their group on any metric (hits, false alarms, or memory accuracy; $n = 18$). The final sample in the statistical analyses consisted of 821 participants split relatively evenly across the six experiment groups (see Table 1).

Materials

Materials in this experiment were taken from the first 40 elements of the periodic table (e.g., Silicon) and their respective symbols (e.g., Si), as well as meaningless letters and letter combinations (e.g., Sv). Stimuli from the periodic table were limited to the first 40 elements as these are likely the most familiar elements to participants. In the Words condition, all stimuli were between 4 and 10 letters long ($M = 7.18$, $SD = 1.50$) and were presented in title case format (i.e., the first letter was capitalized, e.g., "Silicon"). In the Symbols group, the original periodic table symbol format was maintained such that some stimuli were a single letter (11 cases), while others were two letters (29 cases), each also presented in title case format. To enable consistent visual features amongst the different stimuli types, symbols from the periodic table were presented as plain letters, without the presence of a border, atomic number, or atomic weight (as one might find on the periodic table). Meaningless letters were matched to the Symbols stimuli such that the same number of items were made up of single or double letters, and the first letter in double-letter items matched those found in the Symbols list (see Table 2). Additionally, care was

			Sex		Age	
Expertise	**Condition**	***n***	**% Male**	**% Female**	***M***	***SD***
Non-experts	Letters	140	17.9	81.4	21.2	6.3
	Words	135	23.0	74.1	20.5	3.4
	Symbols	134	29.8	69.4	20.3	2.4
Experts	Letters	137	29.2	68.6	20.3	2.4
	Words	138	28.3	71.0	19.8	1.9
	Symbols	137	21.9	77.4	20.0	2.1

Table 1. Demographics of final participant samples across groups. 4 Non-Expert and 6 Expert participants declined to report their ages.

Words	Symbols	Letters
Hydrogen	H	J
Helium	He	Tr
Lithium	Li	Lo
Beryllium	Be	Bt
Boron	B	M
Carbon	C	Q
Nitrogen	N	A
Oxygen	O	T
Fluorine	F	R
Neon	Ne	Nl
Sodium	Na	Nx
Magnesium	Mg	Mj
Aluminum	Al	Ao
Silicon	Si	Sv
Phosphorus	P	L
Sulfur	S	E
Chlorine	Cl	Ct
Argon	Ar	Av
Potassium	K	X
Calcium	Ca	Cw
Scandium	Sc	Sy
Titanium	Ti	Tn
Vanadium	V	D
Chromium	Cr	Cy
Manganese	Mn	Mh
Iron	Fe	Fy
Cobalt	Co	Ci
Nickel	Ni	Nu
Copper	Cu	Cx
Zinc	Zn	Mk
Gallium	Ga	Gs
Germanium	Ge	Gp
Arsenic	As	Az
Selenium	Se	Sk
Bromine	Br	Bg
Krypton	Kr	Kp
Rubidium	Rb	Rm
Strontium	Sr	Sz
Yttrium	Y	Z
Zirconium	Zr	Zf

Table 2. Experiment Stimuli used in each condition.

taken to ensure that none of the meaningless letter stimuli were present as symbols on the entirety of the periodic table. All stimuli in the encoding and retrieval phases were presented in Times New Roman size 48 black font, centered on a white background.

Procedure

Expert and Non-Expert participants were randomly assigned to one of three groups: meaningless letters, words, or symbols. The experiment was built and administered using Qualtrics software. As a result, the study was conducted on participants' personal computers during a single online session. After participants provided written informed consent, they were asked to study and later remember either (1) letters and letter combinations (2) words from the periodic table, or (3) symbols from the periodic table.

During the study phase, 20 items were randomly selected from the 40-item master stimulus list to be presented at encoding, one at a time. During a trial, a randomly chosen target stimulus was presented for 2 s at the center of the screen, followed by a 250 ms blank screen, a 500 ms fixation dot at the center of the screen, and a final 250 ms blank screen.

After all of the 20 stimuli had been presented, participants completed a filled delay task. They were instructed to press 'play' on a media control bar to listen to a tone and then to respond by clicking 'low,' 'medium,' or 'high,' depending on the pitch of the tone. Examples of each pitch were provided in the task instructions. This task was repeated for 2 min and was included to guard against potential ceiling effects by eliminating recency and minimizing post-list rehearsal.

Following the filled delay, participants completed an old/new recognition memory test. Participants responded with the '1' key if the item was 'new' (i.e., not studied previously), or the '2' key if the item was 'old' (i.e., they remembered it from the study phase). All 40 items from the master stimulus list were included on the recognition test (20 targets plus the remaining 20 items that served as lures).

After the recognition test, all participants completed a self-paced task that assessed their knowledge of symbols from the periodic table of elements (regardless of expertise group or condition assignment). On each trial, a randomly selected element from the first 40 elements on the periodic table was presented in word format at the center of the screen. Below the word was a text box which allowed participants to type the symbol (e.g., Au) for the target element word (e.g., Gold). Participants pressed the Enter key to save their response and proceed to the next trial.

Participants then completed Set A of the Mill Hill Vocabulary Scale[20] to assess their English language competency ($M = 16.38$, $SD = 4.38$). Finally, participants answered a yes/no attention check question regarding whether they paid attention during the study, were not distracted, and tried their best (under assurance their credit was already secured). The procedures and materials for this study are in accordance with the Declaration of Helsinki and were approved by the Office of Research Ethics at the University of Waterloo (project #43,948). All pre-registrations, experiment programs, data, analysis code, and other materials are available on the Open Science Framework (OSF; https://osf.io/ur3cq/).

Statistical approach

To examine memory performance across conditions, corrected recognition scores (hit rate minus false alarm rate; hereon referred to as 'memory accuracy') were compared using the *rstatix* package (v. 0.7.2)[21] for *R* (v. 4.3.3)[22]. Effect sizes for *t*-tests (Cohen's *d*) and their 95% confidence intervals were determined with 10,000 bootstraps via the percentile method using the same package. Bayes factors were calculated using the *BayesFactor* package (v. 0.9.12–4.7)[23], enlisting a default Jeffreys-Zellner-Siow (JZS) prior with a Cauchy distribution (center = 0, $r = 0.707$). This package compares the fit of various linear models. In the present case, Bayes factors for the alternative (BF_{10}) are in comparison to null models containing participant as a random effect. Bayes factors for interaction effects are relative to models containing both main effects. Interpretations of Bayes factors follow the conventions of Lee and Wagenmakers[24]. Bayes factors in favor of the alternative (BF_{10}) or null (BF_{01}) models are presented in accordance with each preceding report of NHST analyses (i.e., based on a $p < .05$ criterion) such that $BF \geq 1$. Plots were formed using the *ggrain* package (v. 0.0.4)[25].

Bonferroni corrections were used for all pairwise contrasts reported in the results. Uncorrected contrasts followed the same pattern of effects as the Bonferroni-corrected contrasts reported below, save for one exception: The Non-Expert Symbols group performed significantly better than the Expert Letters group, $t(269) = -2.39$, $p = .017$, $d = -0.29$, CI95[-0.54, -0.06], $BF_{10} = 2$. This makes intuitive sense given that most non-expert participants did have *some* knowledge of the periodic table (see Fig. 1), slightly boosting performance for some of the periodic table symbols relative to meaningless letters.

In our main statistical analyses to follow, participant expertise was based on their completion of an introductory chemistry course. To ensure the reliability of our findings, all analyses were also conducted using a definition of expertise based on a median split of performance on the element-to-symbol labelling task. The pattern of findings was identical to the results presented below, with one exception: When sorting participants into expertise groups based on this new method, memory performance was now better for the Expert Words group relative to the Non-Expert Words group, $t(271) = 3.09$, $p = .033$, $d = 0.38$, CI95[0.14, 0.61], $BF_{10} = 11.81$.

Results

Knowledge of the periodic table

A Welch-adjusted independent-samples *t*-test was conducted to check whether those in the Expert groups had superior knowledge of symbols on the periodic table relative to the Non-Expert groups. Knowledge of the periodic table was operationalized as the proportion of elements (e.g., Hydrogen) for which a participant was able to correctly report the elemental symbol (e.g., H). The *t*-test confirmed that those in the Expert groups ($M = .82$, $SD = .11$) did indeed have superior knowledge of element-to-symbol associations in comparison to those in

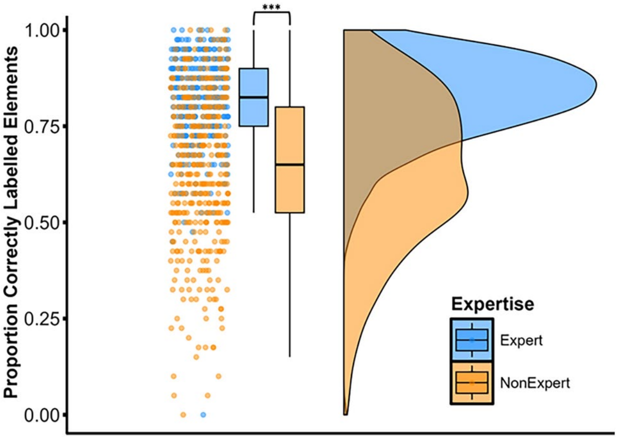

Fig. 1. Periodic Table Knowledge as a Function of Group. *Note*. A comparison of periodic table knowledge as a function of group, collapsed across conditions. Individual data points are presented for each participant, along with smoothed distributions and boxplots. *** = $p \leq .001$.

Expertise	Condition	Accuracy		Hit rate		False alarm rate		Symbol knowledge	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Non-experts	Letters	.45	.25	.72	.16	.28	.16	.58	.20
	Words	.58	.24	.83	.13	.25	.18	.63	.20
	Symbols	.48	.25	.80	.15	.32	.16	.71	.17
	Overall	.54	.24	.80	.14	.26	.17	.82	.11
Experts	Letters	.41	.24	.72	.15	.31	.18	.79	.10
	Words	.60	.22	.83	.12	.24	.17	.81	.13
	Symbols	.60	.21	.84	.12	.24	.15	.87	.10
	Overall	.50	.25	.78	.15	.28	.17	.64	.20

Table 3. Average memory performance and element symbol knowledge across experimental groups.

the Non-Expert groups ($M = .64$, $SD = .20$), $t(641.94) = 16.21$, $p < .001$, $d = 1.13$, CI95[0.99, 1.28], $BF_{10} > 1000$ (see Fig. 1). As expected, Pearson correlations demonstrated that periodic table knowledge was positively correlated with memory accuracy in both the Expert Symbols, $r = .34$, $p < .001$, and Non-Expert Symbols groups, $r = .45$, $p < .001$.

Memory performance

Next, a 2 × 3 ANOVA was conducted with Expertise (Expert, Non-Expert) and Condition (Letters, Words, Symbols) as between-subjects factors and memory accuracy as the dependent measure. The main effect of Expertise was significant, indicating superior memory accuracy in the Expert groups relative to the Non-Expert groups, $F(1, 815) = 4.25$, $p = .040$, $\eta p^2 = .01$, $BF_{01} = 1.77$. This overall difference in memory performance was, however, driven primarily by improved performance in the Symbols group (see Table 3), as expected, and the combination of a marginal *p*-value with Bayesian evidence slightly in favor of the null call this main effect into question.

The main effect of Condition was also significant, indicating differences in memory accuracy between Letters, Words, and Symbols, $F(2, 815) = 34.84$, $p < .001$, $\eta p^2 = .08$, $BF_{10} > 1000$. These main effects, however, were qualified by a significant Condition × Expertise interaction, $F(2, 815) = 8.53$, $p < .001$, $\eta p^2 = .02$, $BF_{10} = 73.59$.

Bonferroni-corrected independent-samples *t*-tests were then conducted to break down the interaction by comparing memory accuracy between each group. In the Letters groups, memory accuracy did not differ by Expertise (as one might expect), $t(275) = -1.37$, $p = 1$, $d = -0.17$, CI95[−0.41, 0.07], $BF_{01} = 6.15$. In the Words groups, memory accuracy also did not differ significantly by Expertise, indicating that both groups could extract semantic information from the full element name, $t(271) = 0.65$, $p = 1$, $d = 0.08$, CI95[−0.16, 0.32], $BF_{01} = 6.15$. In the Symbols groups, however, memory accuracy was higher in Experts than in Non-Experts, demonstrating that knowledge of the periodic table boosted memory for element symbols as their meaning was known to participants, $t(269) = 4.39$, $p < .001$, $d = 0.53$, CI95[0.29, 0.78], $BF_{10} > 1000$.

As predicted, memory was significantly worse for Symbols relative to Words in the Non-Expert groups, demonstrating poor performance for symbols likely driven by a lack of semantic understanding of the target items, $t(267) = -3.45$, $p = .010$, $d = -0.42$, CI95[−0.67, −0.18], $BF_{10} = 34.92$. Critically, however, when participants did have semantic understanding of symbols (in the Expert groups), the difference between Symbols and Words

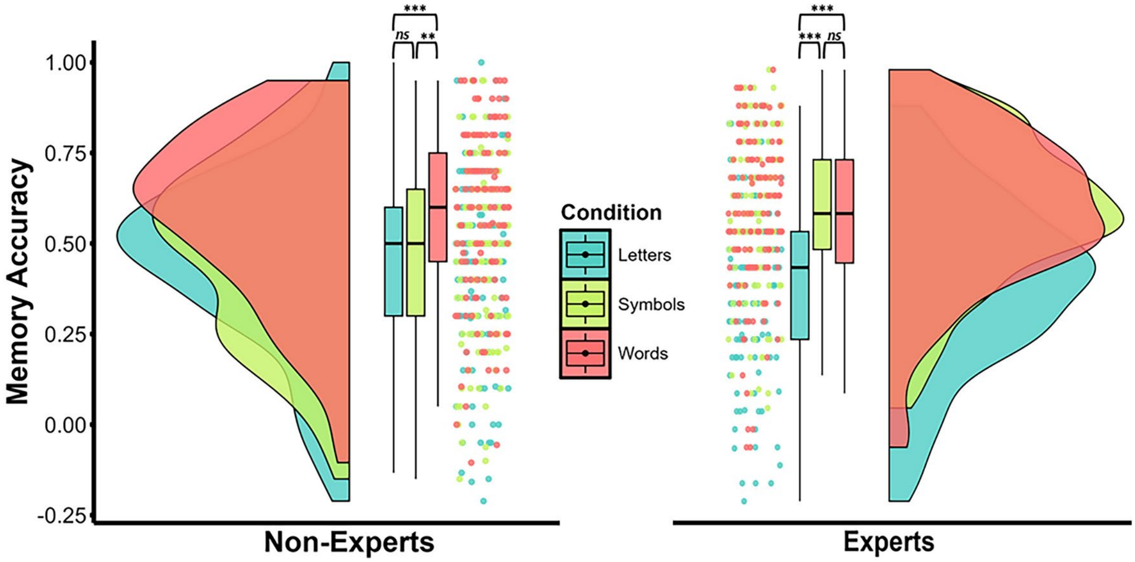

Fig. 2. Memory Accuracy in Each of the Conditions, Grouped by Expertise. *Note*. Individual data points are presented for each participant, with smoothed distributions and boxplots. *ns* = nonsignificant ($p \geq .05$), ** = $p \leq .01$, *** = $p \leq .001$.

was non-significant, showing that knowledge of a symbol's meaning raised memory for symbols up to the level of their word counterparts, $t(273) = 0.01$, $p = 1$, $d = 0.01$, CI95[−0.23, 0.25], $BF_{01} = 7.52$. These two critical findings suggest that while knowledge of what a symbol means is necessary to raise memory performance to match that of words, it does *not* lead to the typically-observed memory benefit for symbols *over and above* words (i.e., the symbol superiority effect; see Fig. 2).

Discussion

In prior studies investigating memory for symbols, semantics were often equated between word and symbol stimuli, while visual content necessarily had to vary between conditions (e.g., $ vs. 'dollar'). Paivio's dual-coding hypothesis[9] posits that when a stimulus evokes two codes during encoding (e.g., verbal and image in the case of pictures), the probability of successful memory retrieval is increased relative to stimuli that only evoke a single code (e.g., verbal in the case of words). It is also argued that, immediately upon viewing images and symbols, they are automatically labelled (e.g., when one sees $, they think 'dollar' in their mind), offering a secondary, verbal code in memory. This logic has been used to explain the picture superiority effect in memory for over 50 years[8,14], and has recently been applied to account for the case of symbol superiority in memory as well[1,2]. As a consequence, prior work on the symbol superiority effect assumed that it was the difference in visual content was causing the performance boost observed for symbols[1,2]. However, it remained uncertain whether the effect of *symbolism itself* (requiring an abstraction of the association between a visual symbol and its meaning) could be driving the effect instead.

Here, we sought to determine whether symbolism is what enhances memory for symbols relative to words. To achieve this, we again compared conditions in which semantics were equated (as had been done previously), but now, we used stimuli that also contained highly similar visual features (all were comprised of English letters), and we manipulated knowledge of a symbol's meaning as well (by way of participant expertise). In so doing, memory for a special category of items was assessed: words (e.g., potassium) and symbols (e.g., K) representing chemical elements on the periodic table, with both being compared to a control stimulus set consisting of meaningless letters (e.g., J).

Data from non-expert participants were collected to serve as a comparison group, to ensure that those in the expert group did indeed have higher knowledge of symbols from the periodic table, and that this understanding of symbols' meanings benefitted performance. Memory performance for meaningless letters was also examined to provide a comparison whereby visual content was equated to words and symbols, but meaning was not. In essence, the current paradigm allowed for examination of both the effect of symbolism and prior knowledge of a symbol's meaning on memory, all while holding visual features constant.

We successfully manipulated expertise with the periodic table of elements, as shown by superior symbol-to-word mappings in the Expert groups. We also successfully equated semantics between conditions, as evidenced by the finding that memory for words and symbols did not differ in expert participants, while both led to better memory than meaningless letters. Furthermore, non-expert participants remembered words as well as expert participants, but non-expert participants' memory for symbols and meaningless letters was equally worse than that for words, suggesting that non-expert participants encoded symbols from the periodic table the same way experts encoded meaningless letters.

This study revealed two critical findings that allow us to determine the role of symbolism (knowledge of a symbol's link to its referent) in how symbols are processed in memory. First, it was demonstrated that symbols were remembered worse than words by participants in the Non-Expert groups, in which semantics were unknown. Second, in the Expert groups—in which semantics *were* known—memory for symbols rose to be on par with that of their word counterparts. Thus, the exact same symbols were remembered akin to meaningless letters in non-experts, but were remembered as well as meaningful words in experts. These two related findings provide evidence that symbolism is important to obtain a memory benefit for symbols relative to semantically-void shapes (in this case, meaningless letters), but that symbolism is *not* enough to improve memory over and above that of words (i.e., the symbol superiority effect) on its own.

While this work was the first to isolate the effect of symbolism on memory, it comes with some limitations. First, calling symbols on the periodic table 'symbols' at all may be unintuitive to some, as they are made up of letters. While it is true that this set of stimuli may not come to mind when asked to generate a list of symbols, they should reasonably be considered symbols nonetheless (or at least, ideograms) due to their conveyance of meaning outside reliance on knowledge of a written language system. Our data clearly show that when participants know that a letter has meaning beyond its face value, it is interpreted with that meaning. It is precisely this same harboring of meaning that makes a letter on the periodic table a symbol: It is a character that refers to some idea beyond the character itself.

Perhaps the only difference between the symbols used here and the ones used in previous studies of symbol superiority is that, here, the symbols were made up of letters. That the symbols used here were alphabetical letters may have caused participants to default to a primarily 'verbal' mode of processing. That is, in terms of dual-coding theory, it is possible that symbols from the periodic table of elements do not invoke imagery processing and are instead read as if they were any other word or set of letters. A physical distinctiveness account[6] could also explain these findings: Words and symbols were purposefully highly similar in terms of visual detail (though words were always longer), leaving little distinctiveness available for symbols to stand out in memory on the recognition test. Thus, we posit that it is likely symbols require distinctive visual features to be better remembered than words.

Based on the present findings, it is reasonable to suggest that memory for everyday symbols, like that for poison (☠), differs from words (e.g., 'poison') due to their visual nature, their physical / conceptual distinctiveness, or some other factor. What does *not* seem to largely influence memory, based on our current data, is the effect of *symbolism* itself (and any extra cognitive processing that interpretation of a symbol entails). While knowledge of a symbolic relation was critical for memory of symbols to rise to the level of words, it was not enough to elicit a symbol superiority effect. Future work, therefore, should focus efforts on delineating the effects of visual and semantic attributes on symbol superiority in memory, rather than investigating 'symbolism' as a special type of link between a visual stimulus and its associated abstract referent. For instance, in light of our current results, it seems reasonable to expect that memory for brand logos made up of a single letter (e.g., Amazon, Facebook, Google, Pinterest, Motorola, T-Mobile) may only be as-well remembered as their company name counterparts (although prior work has shown that stylizing letters can boost memory)[6]. Nonetheless, more research on the cognitive and neural processing of symbols is warranted given the novel contributions of such work to psychological science, as well as the immediate applications of those insights to graphic design and advertising.

In conclusion, it was recently shown that symbols are better remembered than both their word counterparts, as well as unrelated concrete nouns—the *symbol superiority effect*. This robust finding has now been demonstrated with common everyday symbols (e.g., !@#$%)[1], as well as sports team logos[2]. Until now, however, it was unclear whether this benefit to memory was due to the fact that symbols allow for the representation of abstract ideas with a distinctive concrete visual device, or whether the processing of a *symbolic link* between an abstract idea and its referent was benefitting memory. Here, we investigated this by assessing memory for elements on the periodic table in both word form and symbol form, and compared it to memory for meaningless letters. Because both semantics and visuals were equated in the words and symbols conditions, only the degree of symbolic representation differed. Our results clearly demonstrate that while knowing what a symbol means can enhance memory relative to semantically-void letters, the processing of symbolism in and of itself does not enhance memory performance for symbols above that of words. Therefore, an intriguing exception to the symbol superiority effect has been uncovered; memory for symbols is not *always* better than memory for words. Rather, it is important for symbols to be differentiated from words in some other way—perhaps visually—in order to elicit a memory benefit.

Data availability

All pre-registrations, experiment programs, data, analysis code, and other materials are available on the Open Science Framework (OSF; https://osf.io/ur3cq/).

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Author contributions

All authors contributed to conceptualization of the study. BRTR programmed the study, collected and analyzed the data, and prepared the first draft. BRTR. also conducted the visualization and project administration, with SHNT. contributing to project administration. SHNT. and MAF. edited subsequent drafts. MAF. provided funding and supervision. All authors reviewed the manuscript prior to submission.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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