Title: Size matters – larger images are better remembered

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Abstract: We are constantly exposed to multiple visual scenes, and without intentional effort to memorize or encode them, only some are remembered. It has been suggested that such non-intentional memory is influenced by the depth of processing, but it is unclear whether this applies to visual images. Here we reasoned that bigger images may entail deeper level of processing and will thus be remembered better. In a series of image-viewing experiments we found that larger images were better remembered, image memorability was proportional to image size, faces were better remembered, and outdoors the least. While multiple factors affect image memorability, here we show that under incidental exposure without an encoding task, a basic physical image dimension plays an important role. These results could have significant implications to multiple domains as learning, education, aging, medical care and policies, transport and others.

Main Text:

We are constantly exposed to many images, and despite not making intentional efforts, some of these images are burned into memory while others are not. It is yet unclear what determines image memorability under such unintentional (incidental) conditions. Studies in the linguistic-lexical domain suggest that the "level of processing" of a stimulus determines its memorability (as when attending to fonts ("shallow"), words are less remembered than when attending to their semantic ("deeper") aspects (*1, 2*)). Since visual perception is assumed to be size invariant (*3, 4*), image size is typically not considered as a factor influencing memorability. Here, in contrast to this view, we hypothesized that despite size invariance in visual perception, stimulus size may contribute to the level of processing and thereby influence memorability such that larger images would be remembered better (Fig. 1A).

We tested this in an extensive set of five experiments (n=117). Each experiment started with passive viewing of images of different sizes (exposure phase, see Figure 1B) where participants were asked to freely view the images presented without being aware of any memory related task, and this was followed by an old/new recognition test phase with mid-sized images (see Figure 1C). In Experiment 1 participants (n=17) were exposed to 80 small (3° x 3°) and 80 large (21° x 21°) colored images that appeared in 4 blocks (large-small-small-large; each image presented for 2s, Figure 1B) and then were asked to make old/new memory judgements on a set of 320 mid-sized images (160 old, the old and new matched in contents, randomly ordered, 500ms exposure, 8° x 8° (midway between the small and large images when accounting for the cortical magnification factor, see Supp. Mat.) (*5, 6*))). Accuracy for larger (21°) images was significantly higher than for smaller (3°) images (Figure 1D, small: 44.6% ± 4.4% (SEM), large: 62.9% ± 3.7% (SEM), small vs. large $p = 0.00027$, $t(15) = 4.73$, paired 2-tailed). To rule out the

possibility that the results may have been driven by specific images, a new group of participants (n=16) ran the same experiment but with the small and large image sets switched (Experiment 2). Accuracy for larger images was again significantly higher than for smaller ones indicating that Exp. 1's results were not driven by specific images (Figure 1E, small: 38.7% ± 4.1% (SEM), large: 56.3% ± 5.1% (SEM), $p < 10^{-5}$, $t(14) = 6.84$, paired 2-tailed). To rule out the possibility that the results of Experiments 1 and 2 were driven by recency or primacy effects (*7–13*) as the larger images were presented in the first and last blocks, a new group of participants (n=17) underwent the same experiment but while swapping block order (small-large-large-small, Experiment 3). Here too, we found that accuracy was higher for the larger images regardless of block order (Figure 1F, small: 53.2% ± 3.9% (SEM), large: 63.5% ± 3.3% (SEM), $p = 0.0011$, $t(15) = 4.04$, paired 2-tailed). Since screen resolution may degrade the information conveyed in small images, in Experiment 4 (n=16), on top of the large (21°) and smaller images (3°) that were presented from the same viewing distance and spatial resolution as before (60cm), a new condition of high resolution small images was included. The high-resolution small images occupied the same visual angle as before (3° x 3°) but were based on large images presented from afar and thus while occupying the same visual angle provided much higher ($x6.6^2$) spatial resolution. We found no difference between the accuracy in the small regular-resolution and the small higher-resolution conditions and as in Experiments 1-3 accuracy for larger images was higher than for smaller ones with higher resolution (Figure 1G, small (regular resolution, as in Exp. 1-3) 47.9% ± 4.2% (SEM), small (high-resolution) 43.9% ± 3.9% (SEM), large 61.7% ± 4.9% (SEM), small (regRes.) vs. small (highRes.) $p > 0.168$, $t(14) = 1.45$, small highRes. vs large $p = 0.00017$, $t(14) = 5.058$, paired 2-tailed), indicating that resolution was not likely to be the main factor influencing our results.

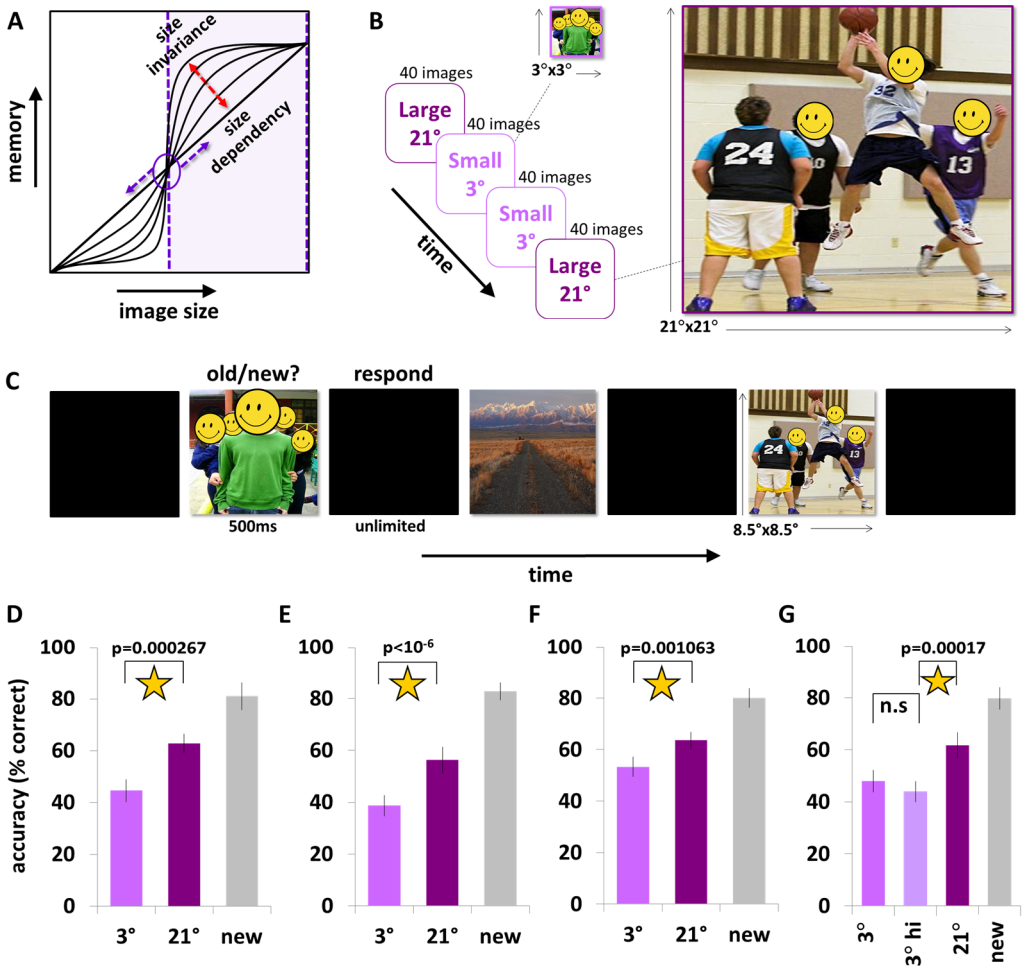

Fig. 1. Model, experimental paradigm and results of Experiments 1-4. (A) Hypothesized dependency of image memory on image size, ranging from size dependency to size invariance. (B) During the exposure phase participants viewed 80 small (3°x3°) and 80 large (21°x21°) images (2s each) presented in 4 blocks of 40 images each. Participants were instructed to freely view the images without any memory or encoding instructions (see more details in text and Methods). (C) The test phase that followed the exposure phase included 320 mid-sized images (~8°x8°, 500ms each, 160 presented in the exposure), and participants were asked to report whether they recall seeing each image or not. (D)-(G) Test phase results reveal that in all experiments the images presented in larger format during the exposure phase were better

remembered than the images presented in smaller format, and this was true in Experiment 1 (D), when we controlled for image sets in Experiment 2 (E), when we changed block order to control for recency or primacy effects in Experiment 3 (F), or when we controlled for reduced resolution in Experiment 4 (G). Error bars represent SEM. Note that smileys were added to cover facial identities in this image (in (B) and (C)) to comply with bioRxiv policy.

To parametrically investigate the effect of image size on memorability and the effect of visual categories on memorability we built a new 4 sizes (height and width of 3°, 6°, 12°, 24°) x 4 visual categories (faces, people, indoors and outdoors) experiment (Figure 2A). We used images with predefined memorability scores (*14*), and image sets of each experimental size had equal memorability scores and equal contribution of each visual category (Figure 2A,B). Two new groups (n_1=25, n_2=26) underwent two versions of this experiment (image sets switched between the size conditions, see Methods). Since there was no effect of experimental version and no interaction between size and version (Table S2) we collapsed the data across the 2 versions. We found a main effect of image size on memory (Figure 2C, $F(3,150)=57.31$ $p<0.0001$) with 3°<6°<12° (p's<0.0001, Table S2). There was also a main effect of visual category on memory ($F(3,150)=15.76$ $p<0.0001$) with faces most memorable and outdoor scenes the least (Fig. 2D, Table S2). Image memorability scores (*14*) were significantly correlated with the actual memory performance (Fig. 2E, Table S3). Since each image appeared in one version as bigger and in the other as smaller, we examined for each image if size had any effect on its memorability by comparing performance between the two versions. This per-image analysis revealed that the images were significantly better remembered if they were presented in bigger format (Fig. 2F-H) and this was true whether there was a big presentation size difference (Fig. 2F,H, 24° vs 3°: t(79)

= 13.0, $p < 10^{-20}$) or a smaller one (Fig. 2G-H, 12° vs 6°: t(79) = 5.58, $p < 10^{-6}$). We also found that the highest accuracy across all experiments was to the new (unseen) images (see Table S1 and Figs. 1D-G, 2C,D), and no priming effects (implicit or explicit) were found (Tables S4-S5).

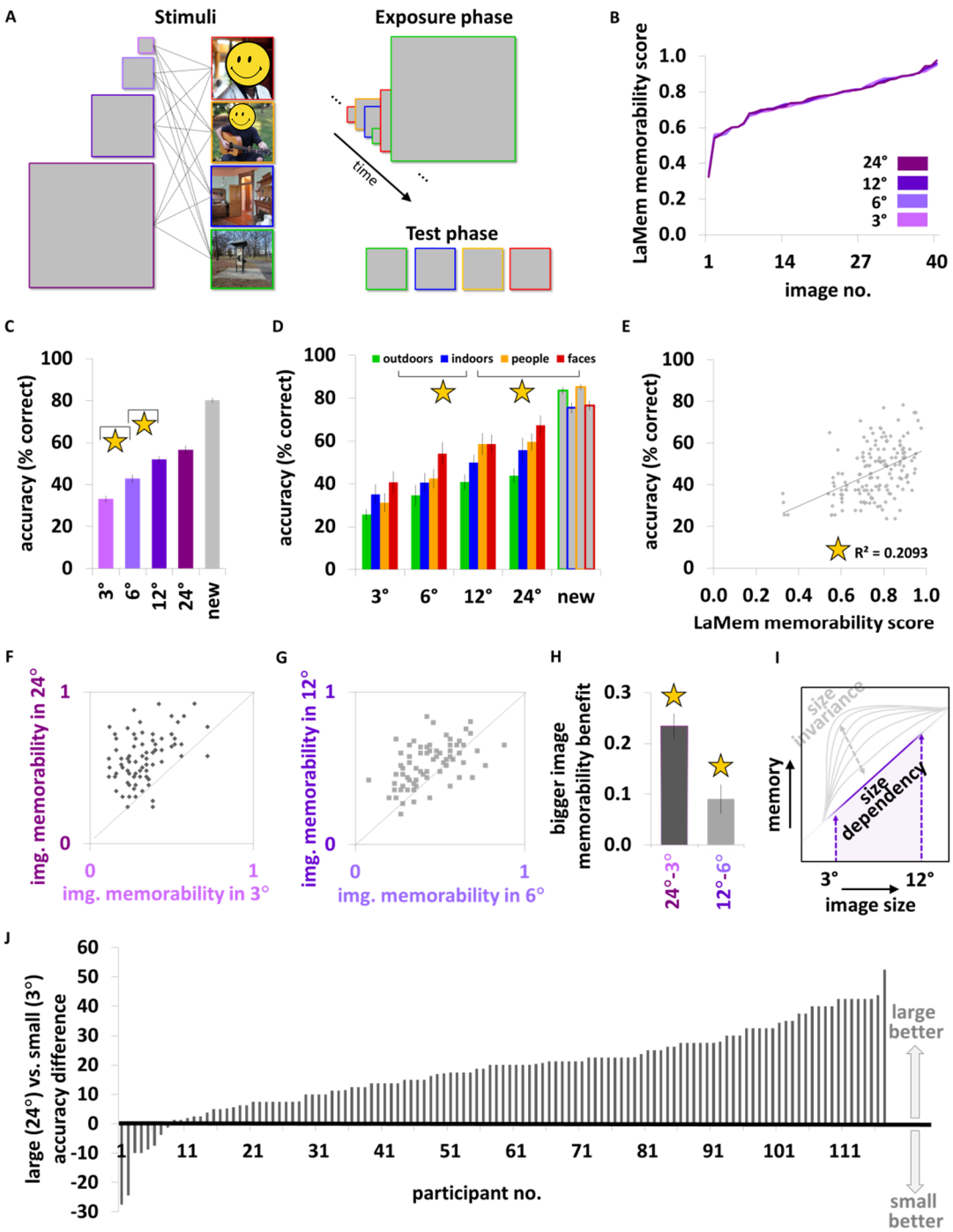

Fig. 2. Experimental paradigm and results of Experiments 5. (A) Participants (n=51) viewed 4 blocks (40 images/block) of 40 uniformly sized images (either 3°x3°, 6°x6°,12°x12° or 24°x24°, 2s each, all from LaMem (*14*)) from 4 visual categories (faces, people, indoors and outdoors). Note that smileys were added to cover facial identities to comply with bioRxiv policy. Experimental instructions as in Experiments 1-4. In test phase 320 mid-sized images (160 old, ~8°x8°, 500ms each) were presented. (B) Image memorability scores (*14*) were equally distributed across the experimental size conditions. (C) Significant effect of image size on image memory was found with images of 24° and 12° best remembered, 6° less, and 3° the least (Tables S4, S5). (D) Significant effect of visual category was found with faces and people best remembered, indoors less, and outdoors the least (Tables S4, S5). (E)-(H) Per-image analyses. (E) Image average accuracy across participants was significantly correlated with LaMem image memorability scores (Table S3). Images were better remembered if they were presented at 24° relative to 3° (F, H) or at 12° relative to 6° (G, H). (I) Our results indicate that unintentional incidental memory of images is size dependent for images of sizes 3°-12°. (J) Large (21/24) vs. small (3) image memory difference for all study participants. Error bars represent SEM.

Our results show for the first time that physical dimension as image size has significant effect on incidental memory of images. This challenges the assumption that visual memory that relies on visual perception is also size invariant. Note that we did not employ the classic incidental memory paradigm involving incidental encoding of images (e.g. *15*, *16*) or any intentional encoding (e.g. *17*, *18*). Rather, there was no encoding task and thus our results may not be

comparable to earlier incidental or intentional memory studies (e.g. *17*, *19*, *20*). In addition, our old-new memory task on one item at a time may have further contributed to the consistently lower memory performance we found across our experiments relative to earlier encoding based findings (e.g. *17*, *18*, *21*). In line with earlier studies (*14*, *22*, *23*)**,** we found that face images were best remembered, and this was true across image sizes (limited to the categories and sizes we used), which could possibly be attributed to their social significance (*24*, *25*). The size-memorability apparently linear relation we found in the size range that we investigated (3°-24°, Fig. 2C, I, and J for individual data (n=117)) may not generalize to bigger or smaller images. In fact we hypothesize that there would be a sharp drop in performance for images smaller than 3°, as well as for images that are "too big" to be perceived, as when viewing a movie from the first row in the cinema.

The size effect on memorability may be attributed to larger expanse of retinotopic cortex responding to bigger images, different eye movement patterns, different spatial frequency contents across the different sizes, different spatial integration, attention, saliency or amount of details involved, all which may influence the level of processing. While our results may be limited to incidental memory and may not generalize to active memory paradigms, our study does demonstrate that physical image dimension can affect image memorability. However, it does not imply that other physical dimensions would have similar effects, or that other non-physical factors (e.g. cognitive) do not play a role in image memorability.

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study, SM prepared and ran the experiments, OP assisted in preparing the experiments, SM, SGD, and OP analyzed the data, SGD, OP and SM wrote the paper, all authors approved the submitted version of the paper; **Competing interests:** All authors declare that they have no competing interests; and **Data and materials availability:** All data is available in the manuscript or the supplementary materials.

Materials and Methods

Participants

A group of 117 participants took part in the study, each participated in only one experiment (17 in Experiment 1 (12 women, aged 28.1 ± 6.9 year, 15 right handers), 16 in Experiment 2 (10 women, aged 25.4 ± 6.0 year, 15 right handers), 17 in Experiment 3 (11 women, aged 25.1 ± 5.7 year, all right handers), 16 in Experiment 4 (10 women, aged 25.7 ± 6.3 year, 15 right handers), and 51 in Experiment 5 (26 in version 1, 25 in version 2, 31 women, aged 25.6 ± 6.6 year, 46 right handers)). The experimental protocols were approved by the Bar Ilan University Ethics committee. All the participants signed a written informed consent before their participation. All participants had normal or corrected to normal far and near vision (all were checked for near and for far visual acuity before the experiment began).

Experiments

All experiments were conducted in a dark room on an Eizo FG2421 24" HD LCD monitor with 1920×1080 pixels resolution running at 100 Hz (Experiment 4 was conducted on an Asus VG248QE 24" monitor with 1920x1080 pixel resolution running at 144 Hz) using an in-house developed platform for psychophysical and eye-tracking experiments (PSY) developed by Yoram S. Bonneh (*26*) running on a Windows PC. Viewing distance was 60cm from the screen in all experiments and conditions except for small highRes condition in Experiment 4 (see details in Experiment 4). Each experiment took approximately 25 min. ANOVA statistical analyses were performed with StatView software 5.0.

Experiment 1

At the exposure phase, 160 images (coloured photographs) of the study set were presented in four blocks (each block of 40 images) in the following block order: Large Small Small Large (see Figure 1), image order within each block was randomized. Small images subtended a visual angle of 3.15°x3.15°, large images 20.78°x20.78°. Images were presented in a sequence, each image displayed for 2s followed by a 500ms black screen inter-stimulus interval, no response was required. Participants were asked to freely view and attend the images (fixation was not superimposed on the images, no fixation was required). All images were taken from the internet and resized to equal width and height (800x800 pixels) to avoid within- and across- condition size differences. These uniformly sized images were then scaled to be displayed according to the experimental condition (small or large). The images included different visual categories (faces, people, hands, animals, food, flowers, indoor places, outdoor places, and vehicles) and the images of each visual category were distributed equally between the small and large image sets.

The test phase followed the exposure phase, and participants were required to perform an old or new image memory task on 320 mid-sized images (visual angle of 8.39°x8.39°, see 'Test phase image size' below, 160 'old' (previously seen in the exposure phase), 160 'new') that were presented sequentially in random order. Each image appeared for 500ms followed by a black screen, participants were required to report if they recalled seeing each image (old) or not (new) without time limitations, no feedback was given.

Experiment 2

To rule out the possibility that specific images may have biased the results of Experiment 1, in this experiment, the experimental protocol was precisely the same as Experiment 1 except that

the image sets of the small and large conditions from Experiment 1 were switched (images displayed as small in Experiment 1 were now displayed as big and vice versa).

Experiment 3

To rule out the possibility that the results of Experiments 1 and 2 may have been biased by recency and primacy effects (*7-13*) (as the large blocks appeared first and last), here we wanted to check whether the presentation order, where large images appeared first and last, does not affect the memorability of the images. Therefore images were assigned to blocks as in Experiment 1 but block order in the exposure phase was changed to Small Large Large Small. This allowed us to examine if size affects image memorability despite possible primacy or recency effects for small images.

Experiment 4

In this experiment we wanted to rule out the possibility that the reduced memorability for smaller images may have resulted from degraded resolution for the smaller images relative to the larger images, especially given the screen pixel limitations. Therefore in this experiment we included, as in Experiments 1-3, the small and large conditions from 60cm viewing distance, and in addition a new condition of small images with higher resolution (presented as large images but viewed from 4m to occupy the same visual angle as the original small images condition but provided much higher ($x6.6^2$) spatial resolution). Specifically, the three conditions in the exposure phase included large images (visual angle of 20.78°x20.78°), small images (visual angle of 3.15°x3.15°), and small (higher resolution) images presented as big at 4m so that they occupy the same visual angle (same retinal image size) as the small images (3.15°x3.15°). We

divided the original image set used in the exposure phase (as in Exp. 1-3, 159 out of the 160 images), to six subsets of similar size (3 with 26 images and 3 with 27 images), where each of these subsets had similar types of images (faces, people, places, food, etc.) and was used in one of the experimental blocks in the exposure phase. The exposure phase took approximately one minute longer since participants were required to move to a distant position for the small higher resolution condition. Participants responded via remote mouse across the experiment. Of the 16 participants that performed this experiment 6 participants underwent the Small Small(highRes) Large Small Small(highRes) Large block order, 6 participants underwent Small(highRes) Large Small Small(highRes) Large Small block order, and 4 performed the Large Small Small(highRes) Large Small Small(highRes) block order to counter balance condition order and so that each condition type would appear in a first block and in a last block of one of the versions. In the test phase 318 images were presented from 60cm at a visual angle of 8.39°x8.39° as in Experiments 1-3.

Experiment 5

Here we wanted to parametrically investigate the effect of image size on memorability. In addition we also tested for visual categories' effect on image memorability resulting in a four sizes (3°, 6°, 12°, 24° height/width) by four visual categories (faces, people, indoors and outdoors) design (Figure 2A). Images were taken from the "LaMem" database with per-image memorability scores (*14*) and were all resized to 900x900 pixels to avoid within- and across-condition size differences. These uniformly sized images were then scaled to be displayed according to the experimental condition (3°, 6°, 12°, 24°). We made sure that for each visual category (faces, people, indoors and outdoors) the memorability scores for that category across

size conditions would be uniform (Figure 2B) and this assured that memorability scores across sizes would be comparable. A group of 25 participants ran version 1 of the experiment, 26 participants ran version 2. Image sets assigned to 3° condition in version 1 were assigned to 24° condition in version 2 and vice versa, image sets assigned to 6° condition in version 1 were assigned to 12° condition in version 2 and vice versa. Block order in each run (i.e. participant) regardless of version was randomized. The experiment was performed at a viewing distance of 60 cm.

The exposure phase included 160 images presented in 4 blocks, each of a fixed specific size (3°, 6°, 12°, or 24°) that included 40 images (10 from each visual category), block order and image order within blocks were random. As in Experiments 1-4, each image was presented for 2sec followed by a black screen of 500ms. Task was to view and attend the images. No response or fixation were required.

The test phase that followed included 320 mid-sized images (160 old, 160 new, visual angle of 8°x8°, see 'Test phase image size' below) that were presented sequentially in random order and participants were required to report for each image if they recall seeing it earlier ("old") or not ("new"). Each image was presented for 500ms after which a black screen appeared until a response was given (there was no time limit). No feedback was given.

Test phase image size

In order for the test phase images to be unbiased towards the small or large images, we aimed to present them at an intermediate size that would be midway (size wise) between the small and large images but in cortical rather than in retinal space. Taking into account the cortical magnification factor (CMF) that enhances foveal representations while reducing

peripheral representations, we chose the midsize to be of a factor *a* bigger than the smaller images and a factor *a* smaller than the larger images such that 3° x a^2 =21° for Experiments 1-4 (resulting in test phase image size of 8°), and 3° x a^2 =24° for Experiment 5. Based on the estimates for M given in earlier studies (5, 6) we used 2 equations that estimate the magnification factor in human's V1 (M_{linear} = 17.3/(E+0.75) by (*5*) and M_{linear} = 29.2/(E+3.67) by (*6*)), both yielding similar results for the test phase image size: 8.5° (Experiments 1-4) and 9.5° (for Experiment 5). Thus the choices of 8.39°x8.39° as the size for the test images in Experiments 1-4 and 8°x8° in Experiment 5 were slightly closer (in cortical space) to the size of the smaller images and thus unlikely to bias the results in favour of the bigger images.

Visual angle		3°		6°	12°	21° / 24°	New
Exp. 1 (n = 17)		44.63 ± 4.35				62.86 ± 3.65	81.02 ± 5.26
Exp. 2 (n = 16)		38.67 ± 4.05				56.38 ± 5.05	82.81 ± 3.32
Exp. 3 (n = 17)		53.24 ± 3.85				63.53 ± 3.27	80 ± 3.68
Exp. 4 (n = 16)		regRes	highRes			61.70 ± 4.94	79.78 ± 4.25
		47.94 ± 4.20	43.93 ± 3.93				
Exp. 5 (n = 51)	**All categories**	33.1 ± 2.27		42.9 ± 2.48	51.96 ± 2.93	56.6 ± 2.49	81.2 ± 1.77
	Faces	40.6 ± 3.46		54.1 ± 3.71	58.63 ± 3.74	67.25 ± 3.18	81.23 ± 2.18
	People	31.4 ± 3.52		42.35 ± 2.93	58.43 ± 3.63	59.61 ± 3.49	86.67 ± 1.92
	Indoors	35.09 ± 3.24		40.59 ± 3.23	50 ± 4.09	55.69 ± 3.38	74.56 ± 2.58
	Outdoors	25.29 ± 3.47		34.7 ± 3.8	40.78 ± 3.48	43.92 ± 3.77	83.82 ± 2.4

Table S1.

Accuracy performances - Experiments 1-5. For each experiment and each condition mean accuracy across participants ± SD.

		T-test			
		Contrast	**Results**		
Exp. 1 (n = 17)		3°, 21°	t(15) = 4.732 **p = 0.0002**		
Exp. 2 (n = 16)		3°, 21°	t(14) = 6.85 **p = 10^{-6}**		
Exp. 3 (n = 17)		3°, 21°	t(15) = 4.043 **p = 0.001**		
		ANOVA			
		Factors	**Main effects**	**Interaction**	**Post-hoc (Bonferroni/ Dunn)**
Exp. 4 (n = 16)		Resolution	F(3,45) = 21.13 **p < 0.0001**		
		3°(regRes), 3°(highRes)			p=0.425
		3°(highRes), 21°			**p=0.0009**
Exp. 5 (n = 51)	**Version X Size**	Version (Version1, Version 2)	F(1,196) = 0.21 p = 0.646	F(3,196)=0.12 p=0.94	
		Size (3°, 6°, 12°,24°)	F(3,196) = 16.55 **p < 0.0001**		
	Size X Category	Size	F(3,150) = 57.31 **p < 0.0001**	F(9,450)=1.84 p=0.0593	
		3°,6°			**p < 0.0001**
		6°,12°			**p < 0.0001**
		12°,24°			p = 0.0177
		Category	F(3,150) = 15.76 **p < 0.0001**		
		Faces, People			p = 0.0101
		Faces, Indoors			**p = 0.0004**
		Indoor, Outdoors			**p = 0.0018**

Table S2.

Accuracy statistical analyses - Experiments 1-5. Accuracy analyses. Significant results appear in bold.

Per image memorability (Exp. 5) to memorability scores (LaMem)				
		correlation		
Exp. 5 (n = 160)	**Ver. 1**	r = 0.389	**p < 0.0001**	t(158) = 5.309
	Ver. 2	r = 0.276	**p = 0.0003**	t(158) = 3.622
	Mean (Ver. 1, Ver. 2)	r = 0.457	**p < 0.0001**	t(158) = 6.467

Table S3.

Experiment 5 per image analysis (n=160 images). For each image we calculated its average memorability in each version of Experiment 5 across all participants and compared these results to the LaMeM image memorability scores. Since each image appeared in the 2 versions in 2 different sizes (either 3° and 24°, or 6° and 12°), for averaging across the versions (line 3), for each image we took the average memorability (mean across the 2 versions) approximating its memorability for an average sized image (see Figure 2E).

Visual angle	3°		6°	12°	21° / 24°	New
Exp. 1 (n = 17)	1041.62 ± 53.48				984.5 ± 41.96	947.647 ± 33.33
Exp. 2 (n = 16)	1056.53 ± 53.80				1005.72 ± 50.96	1005 ± 62.99
Exp. 3 (n = 17)	954.56 ± 41.58				934.412 ± 40.69	943.12 ± 38.39
Exp. 4 (n = 16)	regRes	highRes			1071.78 ± 61.36	1112.84 ± 66.97
	1101.21 ± 73.99	1118.56 ± 66.48				
Exp. 5 (n = 51)	1055.16 ± 261.8		1041.8 ± 241.2	1003.8 ± 218.0	1034.1 ± 256.8	1044.8 ±237.7

Table S4.

Reaction time performances - Experiments 1-5. For each experiment and each condition mean RTs across participants ± SEM. We did not find any explicit or implicit priming effects (see also Table S5).

		T-test		
		Contrasts	**Results**	
Exp. 1 (n = 17)		3°, 21°	t(15) = 2.380 **p = 0.031**	
Exp. 2 (n = 16)		3°, 21°	t(14) = 2.186 **p = 0.046**	
Exp. 3 (n = 17)		3°, 21°	t(15) = 1.025 p = 0.321	
		ANOVA		
		Factors	**Main effects**	**Interaction**
Exp. 4 (n = 16)		Resolution	F(3,45) = 1.321 p = 0.279	
Exp. 5 (n = 51)	**Size X Category**	Size	F(3,150) = 1.859 p = 0.139	F(9,450) = 0.67 p = 0.7365
		Category	F(3,150) = 0.212 p = 0.8883	

Table S5.

Reaction time statistical analyses - Experiments 1-5. Significant effects are indicated in bold. Note that in the 2 significant findings, the larger images showed faster RTs. Further analyses to examine possible priming effects ((i) testing for RTs of old images as faster than RTs of new images, and (ii) testing for RTs of correctly remembered old images as faster than RTs of non-remembered old images) did not yield any significant findings with the mean or with the median RT in any of the experiments.