Picture Theory, Tacit Knowledge or Vividness-Core?
Three Hypotheses on the Mind's Eye and Its Elusive Size

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Abstract

In this study, we compared hypotheses derived from our interpretation of three imagery theories – picture theory, tacit knowledge and vividness-core. Participants were asked to generate "small" (1.2^{o}), "medium" (11° or 16°), or "large" (91°) images of concrete, everyday objects. Image size varied between subjects in Experiment 1, and within subjects in Experiment 2. Vividness ratings and image latency were measured. According to picture theory, vividness should increase directly with latency, and both should increase continuously with size, in both Experiments. According to tacit knowledge theory, such a continuous increase will occur only in Experiment 2 when the full range of sizes is known to the subjects. According to vividness-core theory, latency and vividness should be inversely related in both experiments, and latency should increase with size in Experiment 1 but not in Experiment 2. Results support vividness-core. Images, we conclude, are primarily derived from memories whose latent activation is reflected in reported vividness, as specified by vividness-core theory.

In the recently revived "imagery debate", one contention has been that *tacit knowledge* can explain the classic findings on the effects of manipulating the size of mental images without the need of postulating visual mental imagery or pictorial representations (Pylyshyn, 2002). In the classic study, Kosslyn (1975) verbally cued participants to imagine an animal (e.g., tiger) so that the entire visual image would fill one of four randomly presented squares of different areas. Latencies were longer for generating images that filled larger squares, suggesting to Kosslyn that more time was consumed to "fill out" the larger images with the imaged object parts, and, hence, with more details. According to Kosslyn's (1994) *picture theory*, images are depictive representations formed in a structure (visual buffer) that has space limits, which constrain image resolution. If the object is imagined so small (or so large) that one cannot appropriately represent a part in which a given detail belongs, then the detail will not be incorporated. As size increases within an optimal range, it will offer progressively more locations for representing details of the imaged object, thereby requiring continuously more time to be completely fleshed out.

However, this direct relationship between size and generation latency of mental images may also be explained by tacit knowledge (Pylyshyn, 2002); if one is asked to generate a small mental image, one may generate it with few visible details because one knows from daily experience that real-world objects that are smaller are less detailed when viewed from far off. One could have generated any image at any size with any level of detail, but one did not, because of one's (tacit) knowledge of how objects look. This is similar to the notion of 'demand characteristics', in that the participant is trying to understand the implications of the imagery task (and does so by relating it to actual visual experience), even though there is no explicit demand from the experimenter.

Paraphrasing Pylyshyn's argument, if we are asked to generate a small image, we are likely to generate it as having fewer visible details than if we are asked to generate it as looming large directly in front of us. If the task of generating a small image, as opposed to generating a large one, entails having fewer visible details, then we can predict the result expected by the experimenter, without the need of assuming that we are actually basing our responses on a real scale of small and large images. The results of indirectly increasing or decreasing image detail by manipulating image size will be obvious and will be as expected by the subject and the experimenter (Pylyshyn, 2002, p. 163).

Pylyshyn's and Kosslyn's claims have implications for the data we report, which concern both the time required to generate an image or *image latency*, and the amount of detail (detailedness) and clarity of the mental images, that is, their *vividness* (Marks, 1973). Although Kosslyn and Pylyshyn did not explicitly use the construct or term of vividness in their theories, other researchers have shown that introspectively available properties, such as the ones included in the present definition of vividness, can reflect the resolution of the visual buffer (e.g., Dean & Morris, 2003). In particular, vividness ratings can provide a reasonably good estimation of image detailedness (D'Angiulli, 2001). Thus, it seems that, together with image latency, vividness could be used to derive new interpretations and hypotheses from picture theory, tacit knowledge or other imagery accounts, providing also a common test bench for competing hypotheses.

Indeed, a third alternative account (*vividness-core*) proposes that size manipulations can be confounded with changes in vividness, and that changes in image latency are really related to vividness, not to size. In a study that addressed specifically the relationship between vividness, size and image latency, D'Angiulli and Reeves (2002) found that vividness, not size, had a major effect on image latency, with the most vivid

images being generated 4-5 s earlier than the least vivid ones. In contrast, display size effects were not significant in one experiment and relatively small in a replication. An inverse relation was found in virtually every participant; response latency actually declined with vividness. According to the vividness-core hypothesis, this inverse relationship between vividness and response latency is a central feature of normal image generation, in that vividness reflects the latent state of activation of the visual memory system and the speed in responding with the generation of a mental image is correlated to the level of that activation (Finke, 1980). Size would play an important role only in circumstances which call for extreme transformations such as expanding a tiny image to a giant one (Reeves & D'Angiulli, 2003).

In the two experiments that follow, we compared the hypotheses derived from our interpretations of picture theory and tacit knowledge to the vividness-core account.

Experiment 1

We attempted to replicate Kosslyn (1975) with three crucial experimental variations: 1) we used a completely between-subject design in which the participants generated particular images at one given size only once (one-trial images), and they did not know that other size conditions existed; 2) we included two conditions in which images had to be generated at larger sizes (16° and 91°) as well as those used by Kosslyn (1.2^o and 11°); and 3) we did not rely solely on image latency, but also on vividness ratings.

With respect to image latency, tacit knowledge seems to imply that a participant could infer quite easily that the image generation task should be rather quick when the target size is tiny, and conversely that the image generation task should be time-consuming when the target size is enormous. However, what would happen if, like in the present case, the participant was asked to generate an image in a single trial, at a *medium* size (11° and 16°), that is, neither 'evidently small' (1.2^o) nor 'evidently large' (91°)?

Participants should be able to infer the demand characteristics more accurately when a relative criterion is made easily available (Keppel, 1982), that is, when medium-sized images are intermixed with small and large ones. In contrast, when these image sizes are taken as a between-subjects factor, with each size fixed in a block of trials, such comparisons will not be readily available to suggest obvious inferences. One way of bringing the general claim that tacit knowledge affects imagery/size relations to bear, is to assume that tacit knowledge is categorical. That is, participants are assumed to have expectations about the appearances of, say, two types of image; small, and large; or possibly three types of image, small, medium, and large. However, the number of such categories is strictly limited. In this case intermediate images will be assimilated to the nearest category, and the effects of size on performance will be discontinuous. In the particular case of two categories, intermediate sizes will be assimilated to 'small' or to 'large'. Thus, for example, if 11°-images were assimilated to the 'small' category and 16°-images to the 'large' one, then latencies for 1.2^o- and 11°-images would be similar, as would those for 16°- and 91°-images.

If, however, the pictorial theory is correct, we should replicate Kosslyn's findings that image latency increases continuously with size, as the participant's response should reflect an absolute size criterion, therefore being of intermediate order between the independent response of a participant generating only tiny images and that of a participant generating only enormous images.

With respect to vividness, one interpretation of Pylyshyn's claims is that tacit knowledge will induce subjects to report large images as more vivid than small ones, provided the experimental instructions do not ask subjects to simulate non-ideal viewing conditions such as imagining objects out of focus or through a fog. Therefore, one may expect vividness to increase with size. Here, the issue associated with medium sizes can be reiterated for vividness as well. Do imagers use an absolute criterion to place more or less detail in an image, as posited in picture theory? If so, will medium-sized images have an intermediate level of vividness between that of small and large images, so that there is a continuous increase of vividness with size?

Both picture theory and tacit knowledge predict a direct relationship between image latency and size, in which vividness is either a covariate (picture theory) or a mediated outcome (tacit knowledge). Thus, vividness ratings should increase with size, continuously if picture theory is correct, but discontinuously if tacit knowledge is correct.

Finally, the vividness-core hypothesis would predict that if image latency will increase with size (whether continuously or not), then vividness will show the inverse trend, namely, it will decrease with size.

Method

Participants. Seventy-four undergraduate students; none had participated in an imagery experiment before.

Stimuli. We selected 40 verbal descriptions used in previous research (D'Angiulli, 2001; D'Angiulli & Reeves, 2002). These verbal descriptions were matched for high vocabulary frequency, imageability and concreteness values (with imageability and concreteness values both high, namely, above 5.0). The descriptions selected included animate beings (e.g., cat, elephant) and inanimate objects (e.g., bottle, refrigerator); preliminary data indicated no reliable differences between these subsets. For images of these stimuli, generated at the smaller display sizes (1.2^o and 11°), mean vividness ratings were strongly correlated ($r_{effect\ size}$ = .75) with mean ratings of the amount of detail (see D'Angiulli, 2001). (Ratings were only weakly correlated for individual images, but in the present study we focus on group averages.) Although about half of the variance in the mean vividness ratings of our images reflects image detailedness, it is probable that other factors such as image color and luminance also contributed to the overall impression of each image (see McKelvie, 1995).

Apparatus and Procedure. Participants sat facing a computer monitor and pressed the right button of a mouse to

display each description and to respond. At the beginning of each experimental session, a black outline square was displayed at centre screen and remained there throughout each trial. The square could have one of four angular sizes (1.2°, 11°, 16° and 91°) fixed for each participant. Participants fixated the middle of the square's upper side. Upon their mouse click, an alerting beep was sounded, followed 250 ms later by a description (e.g. 'table') displayed 0.5 cm above the square. Participants were instructed to read the description silently and as quickly as possible, and then to project an image of the corresponding object, as if seen in the frontal plane from a ¾ side-view, so as to fill the entire square area.

Participants were asked to consider their image as complete or finished as soon as they could not notice any further improvements in its vividness, clarity, or detail. They indicated that the image was complete by clicking the mouse button. The computer covertly recorded the image latency (i.e., time elapsed from the description presentation to the mouse-click indicating image completion). The participants were *not* informed that their manual responses were being timed.

A horizontal array of seven buttons then appeared at the bottom of the screen. Participants clicked on one of the buttons to report the vividness of their image; there was no deadline for the rating response. From left to right, each button was labeled with one of seven vividness level descriptions (i.e., 'no image', 'very vague/dim', 'vague/dim', 'not vivid', 'moderately vivid', 'very vivid', 'perfectly vivid'); which we identify as levels 1 (no image) through 7. Valid trials were defined by vividness ratings > 1; invalid trials (< 2%) were excluded from the data analysis. Participants were also instructed to rate as 1 any failure to imagine as instructed. Care was taken during practice sessions to familiarize the participants with using these vividness ratings. They were instructed to rate the detailedness and clarity of their mental image of a given object as these compared to the ones of the actual percept (Marks, 1973).

Following the rating response, the array of buttons disappeared and the screen reverted just to the square outline in preparation for the next trial. The stimuli were presented in random order with a minimum inter-trial interval of 5 s to minimize imagery persistence between trials (Craver-Lemley & Reeves, 1987).

There were four between-subjects size conditions: 1.2°, 11°, 16° and 91°. The frames were drawn as black outline squares and were displayed on a white Macintosh screen set at low emission. Larger visual angles were obtained by expanding the sizes of the 1.2°- and 11°-square frames, which had been used in previous research (e.g., Kosslyn, 1975; D'Angiulli, 2002).

Results and Discussion

Figure 1 shows means for image latency (top panel) and for vividness (bottom panel), both plotted according to image size. One-way ANOVA tests (with four levels of size) showed that there was an overall effect of size on image latency ($F_{(3, 78)} = 7.25$, $MSE = .11$, $p < .001$) and vividness

($F_{(3, 78)} = 88.67$, $MSE = 54.40$, $p < .001$). The top panel of Figure 1 indicates that although latencies increased with size, the increase was discontinuous. Multiple comparisons on a Tukey HSD test ($p < .05$) confirmed a discontinuous increase. Images generated at 11° typically had longer latency than images generated at 16°, but the latencies of 11°- and 16°-images did not differ from, respectively, the latencies of 1.2° and 91°-images.
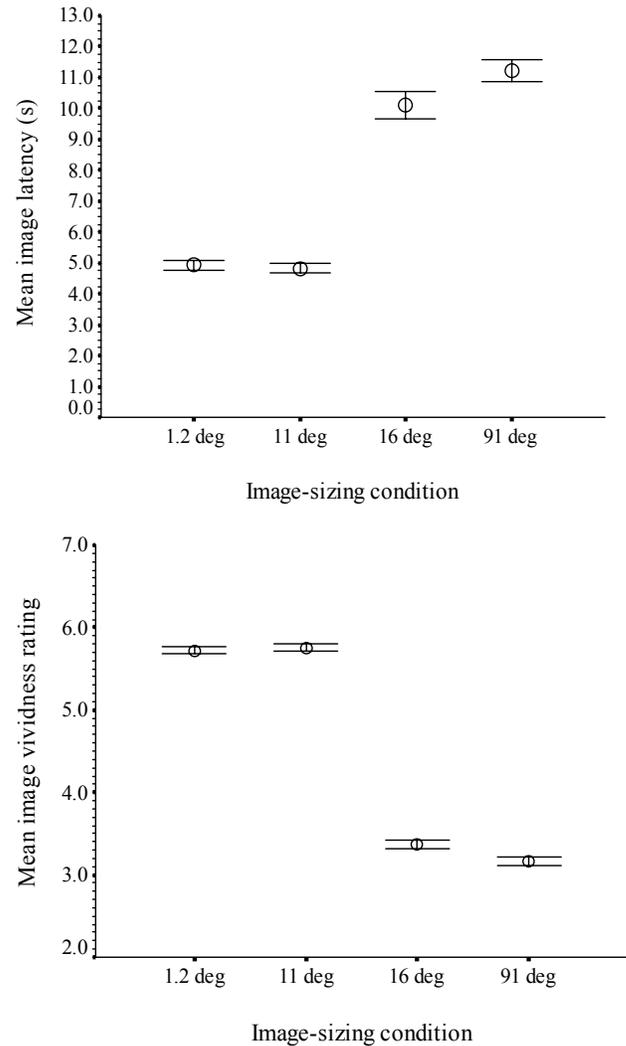

Figure 1: Top Panel: Mean image latencies plotted as a function of the angular sizes used in the image-sizing task of Experiment 1. Bars indicate 1 standard error; deg = degrees of visual angle. Bottom Panel: Mean vividness ratings (min = 2, max = 7) plotted against the sizes used in Experiment 1.

The bottom panel of Figure 1 shows that vividness decreased with size, which contradicts both picture theory and tacit knowledge accounts. Multiple comparisons on a Tukey HSD test revealed the same type of discontinuous effect found for image latencies, but in the inverse direction (i.e., decrease in vividness). That is, images generated at 11° were generally more vivid than images generated at 16°.

Comparing the panels of Figure 1, it is clear that image latency and vividness follow inverse trends, the former increases, whereas the latter decreases with size. Because the overall ANOVA estimated the effects associated with all between-group sources of variation, we tested for trends associated with vividness partialling out the other between-subjects effects. To this end, we performed a polynomial contrast on mean latencies using as contrast weights the z scores of the mean vividness ratings (i.e., .85, .87, -.79, -.93). The contrast showed that image latency and vividness were inversely related (F (1, 78) = 14.23, MSE = .11, $p < .001$). These results support the vividness-core hypothesis, in that the most salient predicted outcome was the inverse relationship between image latency and vividness. Although tacit knowledge could explain the discontinuous patterns, it does not explain the decreasing trend of vividness as a function of increasing size. That smaller images would be more detailed and clearer cannot be derived from knowledge or recall of how things look like in everyday life, since, when compared to close objects, distant objects project smaller and less detailed retinal images. Also, tacit knowledge would not explain the different direction of the effects of size on image latency and vividness.

The present findings remain open to a pictorial re-interpretation, since the visual buffer may contain two spatially-defined regions analogous to the retina's fovea and periphery (Finke & Kosslyn, 1980). Images will be clear if within the fovea (high-resolution), but much less clear if falling onto the periphery (low-resolution). Hence, an object imagined at a small size might fit entirely within the high-resolution region, but the same object might overflow this high-resolution region, and mostly fall onto the low-resolution one, if imagined at larger size. This may explain why vividness would decrease with increasing size. The discontinuous patterns for vividness and image latency could be explained if, in imagery, the high-resolution region could extend between, say, $1°$ and $11°$, and that the boundary between high-resolution and low-resolution regions could be somewhere between $11°$ and $16°$. Further, if image latency co-varied with vividness, our findings would be entirely accounted for by the "mental retina" model. Still, the mental retina account could be explained by tacit knowledge. Because the imagers notice the difference between peripheral and foveal view when seeing a real scene, they might simply use that knowledge to simulate what happens during perception. To contrast tacit knowledge, mental retina and vividness-core accounts, we designed another experiment.

Experiment 2

In Experiment 2, we asked participants to imagine a set of objects projecting their images in displays with increasing visual angle, up to $24°$, across several repeated within-subjects trials, as in Kosslyn (1975; Experiment 5). This experiment was designed to test three sets of predictions.

Because the within-subjects design introduces a relative criterion for judgment one would expect a changed role of tacit knowledge. Thus, the predictions derived from this account would be that: 1) image latency should increase with size; 2) vividness should also increase with size; and 3) the continuous pattern would occur because it can be inferred from knowing the different sizes involved in the experiment (which may be used as points of reference for response and vividness rating). However, if the mental retina hypothesis is correct, we should expect a pattern of result similar to the one found in Experiment 1. Namely: 1) vividness should decrease with size; 2) image latency should increase with size; and 3) the discontinuous pattern will occur, reflecting a drop-off from high to low resolution.

Finally, the vividness-core hypothesis would predict an inverse relationship between vividness and image latency.

Method

Participants. Twenty freshmen undergraduate students.

Stimuli. The same descriptions used in Experiment 1.

Apparatus and Procedure. The apparatus and procedure were identical to the one used in Experiment 1, with the following exceptions. Participants were instructed to read silently the description with an accompanying cue-letter (A, B, C, or D) given on each trial at fixation point, and then to imagine each corresponding object with their eyes open. Each subject read each description 4 times (thus, they imagined 4 sets of the same repeated stimuli) and depending on the trial they had to project the corresponding image in a frame indicated by the cue accompanying the stimulus description. Each letter corresponded to a frame subtending a different visual angle: 5° for cue A, 11° for B, 16° for C, and 24° for D. Prior to the actual experimental trials the subjects were given two practice blocks of an abbreviated version of the experiment. During this period they learned to associate each cue letter with the required display.

Results and Discussion

Figure 2 shows means for image latency (top panel) and for vividness (bottom panel), both plotted according to image sizing conditions. Repeated-measure ANOVA tests (with size as the four levels of the repeated-measure factor) showed that the manipulation of angular size had no overall effect on image latency ($F < 1$), however, it had an overall effect on vividness (F (2, 30) = 14.74, MSE = .35, $p < .001$).

Focused repeated-measure contrasts showed that although there was no difference between image vividness at $5°$ and $11°$ ($F < 1$) there was a vividness increment for larger sizes ($11°$ vs. $16°$: F (1, 19) = 10.75, MSE = .15, $p < .01$; $16°$ vs. $24°$: F (1, 19) = 18.79, MSE = .28, $p < .001$). These results would suggest a discontinuous pattern (contra tacit knowledge) as well as a vividness improvement for images > $11°$ (trend opposite to that expected on the mental retina).
But overall, images were rated below vividness level 4, namely, below 'not vivid'. Therefore, the vividness improvement for the larger images may simply indicate a "spurious" relationship between vividness and size, with no functional role, as it is unrelated to image latency response.

Figure 3: Mean image latency plotted against z scores of the mean vividness ratings obtained in Experiment 2; the angular sizes are shown for each mean.
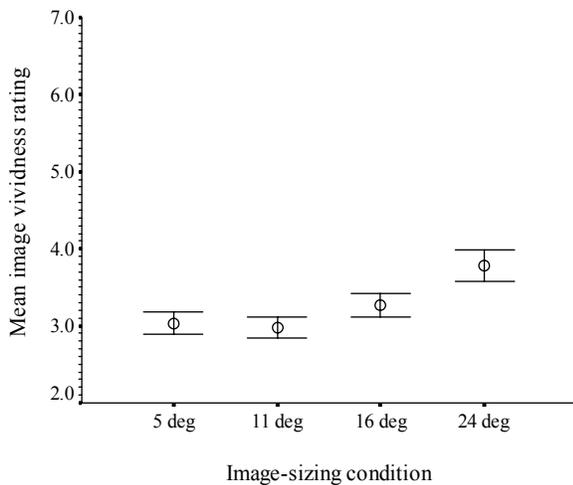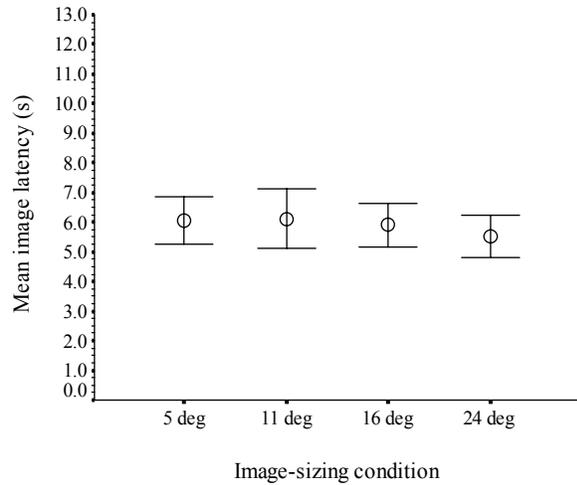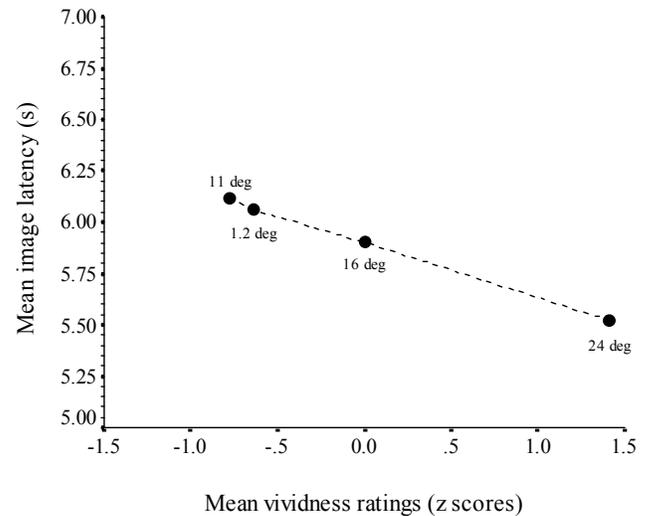
Figure 2: Top Panel: Mean image latencies plotted as a function of the angular sizes used in the image-sizing task of Experiment 2. Bars indicate 1 standard error; deg = degrees of visual angle. Bottom Panel: Mean vividness ratings (min = 2, max = 7) plotted against the sizes used in Experiment 2.

To test the vividness-core prediction of an inverse relationship between image latency and vividness, independent of size, we conducted a polynomial contrast on mean latencies using as contrast weights the z scores of mean vividness ratings irrespective of the order of angular sizes (i.e., -.77, -.64, 0, 1.41). The result of this analysis, represented in Figure 3, confirmed the inverse relationship (F $(1,19) = 23.45$, $MSE = .01$, $p < .001$).

General Discussion

The purpose of this study was to contrast three accounts of imagery – derived from picture theory, tacit knowledge, and vividness-core – by examining the relationships between the manipulation of size, image latency and vividness.

In Experiment 1, participants generated images at one given size, only one time (one-trial images), and they were unaware of the other size conditions. In two of these between-subjects conditions, images had to be generated at "medium" angular sizes (11° and 16°); the other two experimental conditions included very small and very large angular sizes (1.2^o and 91°). Although both picture theory and tacit knowledge predict a direct effect of image size on latency and vividness, using medium sizes allowed us to operationalize a possible difference between these two theories: picture theory predicts a steady, continuous effect of size, but tacit knowledge is likely to be categorical – recall, these participants each experienced only one display size, so they had no obvious point of comparison. The vividness-core hypothesis implies a third, distinctly different prediction. If image latency increases with size (whether continuously or not), then vividness should show the inverse trend. We found that image latency and vividness are inversely related, which supports the vividness-core hypothesis. That vividness shows the inverse trend to that of image latency poses serious threats to both picture theory and tacit knowledge because it implies that small images are relatively more vivid than large images, and this is at odds with ordinary visual perception and our intuition of it.

Together with the inverse latency-vividness relation, in Experiment 1 we also found discontinuous changes in latency and vividness as a function of increasing size. This pattern of results may be interpreted with another picture theory, the mental retina account, which postulates that the imagery medium has a high-resolution region affording mostly "foveal view" for small-sized images (i.e., between 1° and 11°) and a low-resolution region affording mostly "peripheral view" for large-sized images ($>11^o$). Hence, the discontinuous pattern for latency and for its covariate vividness would simply indicate a fall-off in image resolution. In Experiment 2, participants were asked to generate images with increasing angular size across several repeated within-subjects trials. If

the mental retina account were correct we should have replicated the findings of Experiment 1 and find a discontinuous pattern (foveal vs. peripheral view). If the tacit knowledge were true we should have found direct and continuous relationships between image latency and size, and between vividness and size (because, being exposed to all size conditions, the participants may think that the continuous increase should be the most plausible outcome if they were seeing in those conditions). However, in Experiment 2 we found a latency-vividness inverse relation which was independent of size and clearly supported the vividness-core account again.

Experiment 2 also yielded: (a) lack of size effects, and (b) overall lower vividness ratings than Experiment 1. We suggest that the repeated images of Experiment 2 were not constructed ex-novo, like the one-trial images of Experiment 1. Rather, they were retrieved as "carbon-copies" at non-significantly different rates in any size. Accordingly, their visual contents, and vividness, decayed as images were maintained in a temporary 'back up store', similar to the one proposed by Baddeley (2000). Retrieval from this *episodic buffer* (via conscious awareness) may be how the vividness-core is implemented.

One conclusion that is suggested by the present findings is that, contra Pylyshyn, the outcomes of simple image generation tasks such as the one we used are not trivially obvious. We have already discussed how the present findings are counterintuitive. Participant's expectations empirically cannot account for the vividness-latency inverse relationship. After both experiments, our participants (94 collapsed over Experiment 1and 2) were asked to predict a relationship between vividness and image latency, 19% gave a prediction interpretable as a positive correlation (e.g., "if you work more at it your images will become more vivid"). The majority (76%) responded they could not predict any regularity or relationship. Only 5% guessed there would be a negative correlation between the two variables. Virtually the same results were found in another study (D'Angiulli & Reeves, 1998) in which subjects simply judged both 'perceived' speed and vividness of their images using two four-point rating scales. Thus, a more plausible and parsimonious explanation than participants' expectations is that latency as well as the experience of vividness reflect the way mental images are ordinarily generated in everyday life.

In sum, the present study suggests that mental images are not pictures or tacit knowledge but rather already-computed representations episodically stored in memory. These representations seem to require minimal size-adjustment if at all. What seems to make them available is that their latent state of activation in memory is reflected by the reported vividness, we have called this underlying organization of relationships vividness-core. Latent activation of representations is associated with the image generation speed, thus images that are relatively more vivid are also more likely to be generated faster than less-vivid ones (D'Angiulli & Reeves, 2002). The vividness-latency inverse relationship may derive from the adaptive principle that some perceptual-sensory mechanisms react more quickly to more intense or more informative stimulation (Finke, 1980). Therefore, it may have a more general import for imagery than pictorial aspects or tacit knowledge. Notably, it could apply equivalently to all modalities, not just to vision.

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