Can Blue Mean Four?

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1 Introduction

In *Art as Experience*, John Dewey wrote,

> When we perceive by means of the eyes as causal aids, the liquidity of water, the coldness of ice, the solidity of rocks, the bareness of trees in winter, it is certain that other qualities than those of the eye are conspicuous and controlling in perception. And it is as certain as anything can be that optical qualities do not stand out by themselves with tactual and emotive qualities clinging to their skirts. If we hear a rich and haunting voice, we feel it immediately as the voice of a certain kind of personality.

These observations anticipate two concerns at the forefront of contemporary debates in philosophy of mind. Do conscious experiences, experiences that there is something that it is like to have, inform perceivers about the world? If they do, what type of information about the world can conscious experiences convey?

With respect to the first question, a common view is that conscious experiences can carry information or “content” about the world that is of the sort that could be judged to be accurate or inaccurate. This influential idea is sometimes put as the view that conscious experience can be representational. Focusing on the case of conscious
perceptual experience, this paper takes up the question: what sort of information about the world can perceptual experiences carry, or, what properties can they represent?

The most conservative proposal, most often attributed to Tye and Dretske, but probably more widespread than it is commonly taken to be, is that in perception we only represent objects to have so-called low-level properties, those that can be directly transduced by the sensory modalities. For vision, this amounts to shaped colors arranged in some spatial dimension, but not much else. A variety of more liberal proposals have also been offered. Some recognize the representation of properties over and above what the conservative view would allow in a general way. Other accounts support views about the representation of specific “high-level” properties such as causation, being an instance of a natural kind (e.g., a pine tree), uses or functions for a perceiver such as being edible or openable, certain mental states, and even moral properties.

This chapter continues in the vein of such projects. Drawing on the perceptual condition of synesthesia, I argue here that visual experiences can represent visual items as instances of a general type such as a number or letter. From the fact that some synesthetes represent alphanumeric values in perceptual character, we can infer, more generally, that conscious perceptual experiences can represent objects as falling into fairly abstract conceptual categories.
2 Synesthesia

In synesthesia, a stimulus that is typically associated with one sensory modality such as a sound, induces additional modality-specific experiences that are often, but not always, associated with another modality.\textsuperscript{12,13} For example, the sound of a chime could induce a specific color experience (called a color “photism”). While synesthesia often occurs between different sensory modalities, at least one form of synesthesia, grapheme-color synesthesia, is intramodal. Grapheme-color synesthetes systematically experience particular color photisms when presented with particular alphanumeric graphemes such as an “F” or a “4.”\textsuperscript{14}

In many instances of grapheme-color synesthesia, the formal properties of the inducing grapheme seem sufficient to induce synesthetic color experiences. Researchers refer to this as “lower synesthesia.” But in a small subset of grapheme-color synesthetes, color photisms seem to correlate with the inducer’s associated meaning, for example, the numerical value of the grapheme rather than just its shape. This latter phenomenon has been called “higher synesthesia.”

For instance, it has been demonstrated that higher synesthetes have identical color photisms when perceiving diverse symbols that have the same numerical value, for example, an Arabic numeral “5,” a Roman numeral “V,” and an array of five dots all might correlate with blue photisms for a five-blue synesthete.\textsuperscript{15} Moreover, some grapheme-color synesthetes have different color experiences when shown ambiguous graphemes (such as “13”) according to how the grapheme is interpreted. The synesthete
may have a green photism when the grapheme is situated in the series “12, 13, 14,” but a red photism when it is situated in the series “A, 13, C” (presumably when the grapheme is taken as a “B”). This reveals that changes in synesthetic color experiences correlate with changes in the semantic significance ascribed to the grapheme (as opposed to merely its perceived shape). Also, some grapheme-color synesthetes have different color photisms when shifting from attending to an image as a “5” to attending to it as an array of “2’s” (see figure 7.1).

These results provide evidence that some synesthesia is triggered by the numerical values of graphemes. But I want to go a step further and show that these numerical values don’t just trigger photisms; they can also enter into the representational contents of higher grapheme-color synesthetes’ photisms.

3 Synesthesia and Mathematical Savantism

A small subset of number-color synesthetes have demonstrated a heightened ability to store and recall complex numerical information along with an unusual facility with mental arithmetic. These “synesthete-savants,” as we will refer to them, report that color photisms play a critical role in facilitating both abilities. The point here is to demonstrate that the view that their photisms represent numerical values or numbers better explains than alternative proposals the facilitative effect of photisms in their numerical abilities.
British-born Daniel Tammet is one such synesthete-savant.\textsuperscript{18} Tammet reports that he experiences each whole number up to ten thousand as a unique colored shape. He writes, “I can visualize the numbers as meaningful shapes,” and, “my mind perceives numbers as complex, multidimensional, colored and textured shapes.”\textsuperscript{19} Indeed, controlled studies confirm Tammet’s reports by showing that his photisms are both systematic and highly consistent over time, common indicators of the perceptual reality of synesthesia.\textsuperscript{20}

One of Tammet’s unusual abilities is reciting pi from memory up to 22,514 digits. He credits his ability to store and retrieve these digits to his photisms, which he claims facilitate storage by providing a means of chunking numerical information. He writes:

\begin{quote}
It is much easier to conceive of the possibility that a human mind might be capable of recalling over 22,500 consecutive digits of Pi, particularly when, as in my case, it is able to “chunk” groups of numbers spontaneously into meaningful images that constitute their own hierarchy of associations.\textsuperscript{21}
\end{quote}

Although the amount of information retained in memory is limited, “chunking” or consolidating individual items into a single meaningful unit allows us to store a greater amount of information. For instance, we can more easily retain a ten-digit telephone number by grouping the digits into three meaningful chunks (a three-digit area code and so on). Consistent with Tammet’s report, for the synesthete-savant, a single photism
could act as a means to chunk numerical information by representing or carrying information pertaining to a complex number or series of numbers.

Mental arithmetic is another skill at which synesthete-savants such as Tammet excel. Here, once again, nonsavants are limited by a finite memory. To perform mental arithmetic, all of the numerical information concerning the problem to be solved must be retained in working memory while the process of mental computation is completed. This includes both the original problem information as well as all of the intermediary results that are arrived at during the computational process.

Typical nonsavants, however, can only retain three to four items in working memory at a time. This makes it difficult, or practically impossible, for most to work efficiently with large numbers. Recall that while working out a problem such as 42,239 multiplied by 62,349, the digits to be computed as well as the partial results arrived at along the way must all be retained. To see this point, consider how much easier it is to multiply two two-digit numbers than it is to multiply two four-digit numbers, despite the fact that the same mathematical knowledge applies in both cases.

Again, representing numbers by experiences of colored shapes could confer some advantage to the synesthete-savant’s performance of mental arithmetic by providing him or her with an effective means of chunking numerical information. For instance, when Tammet multiplies two four-digit numbers, because he can represent many numbers by a single photism, he need only retain two items in working memory, as opposed to eight.
But although the ability to retain all of the problem information in working memory is necessary for the savant’s extraordinary computational abilities, it is not sufficient. Synesthete-savants are also typically quicker than nonsavants at performing mental arithmetic using smaller numbers that should not put a strain on the resources of ordinary working memory. This is particularly striking when savants are presented with novel, computationally intensive math problems.

Again, Tammet’s self-reports point to the photisms’ facilitative role in the actual process of mental computation. He describes mental computation facilitated by these colored shapes as “rapid, intuitive and largely unconscious.” Moreover, he connects the facilitative role of photisms to the fact that the photisms themselves represent numbers. He writes:

I know these semantic relations between numbers as I know the relations between words, because I can visualize the numbers as meaningful semantic shapes. … Being able to visualize numbers helps me to see and to understand the various interrelations between them.

Theoretical considerations lend some support to Tammet’s reports. Numerical information manipulated during mental arithmetic is encoded and stored in working memory in both verbal and visual formats. Studies show that visually encoded information is more important for mental arithmetic than is verbally encoded information. For instance, it has been demonstrated that people with average and poor mathematical ability differ in their capacities to visually represent numbers in working
memory but not in their capacities to represent them verbally.29 Also, people who score higher in mathematical ability tend to have an enhanced capacity for numerical representation and be more efficient at visually representing.30 31

The idea is that representing numbers with photisms might provide synesthetes with a particularly good means for visually encoding information. Color experiences are likely more vivid than the more typical form of visual encoding by orthographic form and when used in conjunction with form could play a reinforcing role. For instance, study participants report that their mathematical images become less vivid when the visual components of working memory are loaded with visual information irrelevant to the task. Loading also correlates with a decline in arithmetical skill. This correlation between vividness of experience and facility with mental arithmetic is consistent with the fact that more vivid representations of numbers (photisms) can have a facilitating effect on mental arithmetic.

Moreover, the apparently greater vividness of synesthetes’ color photisms could relate to the photisms’ ability to carry more information. The ability to carry more complex information would explain the synesthete-savant’s enhanced computational speed. One promising way of characterizing numerical representations is by the view that such representations are at least partially individuated by, or even identical to, their conceptual roles, the roles they play in cognition, reasoning, decision making, and reporting.32 To represent a specific number, say four, is to have a representation that plays a specific cognitive role. For instance, numbers have relations to other numbers (4
<5<6). We should then expect that numerical representations would play the role of prompting judgments or facilitating reasoning about numbers in a way that reflects these relations.

Numerical representations can be more or less determinate or complex. In this view, a more determinate or complex numerical representation would specify more of the number’s relations to other numbers. More complex representations might, in these subjects, facilitate more complex mathematical reasoning by prompting judgments about more of the numbers’ complex relationships to other numbers. The synesthete-savant may differ from nonsavants, then, because photisms enable them to have very complex and determinate numerical representations of even very large numbers that carry information about the complex ways those numbers relate to other numbers. Because the savant’s numerical representations would already specify this complex set of relations, the savant’s mathematical reasoning can be very quick and automatic. In summary, the hypothesis offered is that vivid photisms that exploit the resources of visual memory can carry more information about numbers by representing more cognitive roles relating numbers to other numbers.

Some synesthete-savants report that photisms facilitate their heightened ability to retain numerical information and to very quickly perform highly complex mental computations. Some empirical considerations have been offered to show how representing numbers by photisms might enable synesthetes to circumvent some of the limitations on these skills by providing an effective means for chunking and by
representing information about a number’s complex relations to other numbers, facilitating quick arithmetical judgments.

4 Inferentialism and Associationism

The previous section offered a view on how photisms’ representation of numbers could explain their facility with the performance of mental arithmetic. That view is also consistent with self-reports of synesthete-savants, who attribute their abilities to their color photisms. An alternative explanation, however, may be that photisms themselves don’t represent numbers, but rather that synesthete-savants represent numbers in the content of independent thoughts that are derived from photisms. The aim of this section is to cast doubt on the adequacy of this alternative account. If the representational view can account for the facilitative role of photisms, and the alternatives cannot, then the reasonable thing is to adopt the representational view.

Let’s consider the alternative view. There are two kinds of cognitive processes by which the representation of numbers might be derived from the photism. Representations of numerical value could be derived from percepts by a routinized associative process—a percept of a numeral “4” leads automatically to a four-belief. Or, based on the photism together with a background belief, we could actively infer that a digit is a certain number, say a “4.” We will assume that by inference we mean conscious inference. If the inference were automatic and preconscious, then this view could likely be reduced to the former associative view.
To start, the inferential view is particularly untenable. For one thing, this view is not consistent with Tammet’s self-reports about his experience. Tammet describes his mental computations as “rapid, intuitive, and largely unconscious.” While it is possible that Tammet’s reports do not reflect his mental reality, all else being equal, it is customary to prefer a theory that grants authority to self-reports.

There are additional problems with this view. Synesthetes are subject to special Stroop effects, showing that associations of numbers with colors are accomplished very early in perceptual processing. Higher number-color synesthetes were shown indicators of numbers such as a hand displaying a particular quantity of fingers painted in various colors. They were quicker at identifying the quantity of fingers displayed when they were painted the color ordinarily associated with that number. This suggests that numbers associated with photism color are processed and influential prior to conscious judgments.

Inference is also more cognitively costly than association, and not only are associative processes quicker, they are oftentimes more accurate. For these reasons, it is advantageous for the cognitive system to connect commonly performed inferential processes with routinized associations. Much of learning is just that—a set of propositions and various if-then relationships internalized and routinized into a set of associations. The result is an expertise or skill. If this happens in most commonly repeated inferences, then there is reason to think that it would happen in the case of higher synesthesia as well.
Can, then, the associative view better explain the computational advantage conferred by photisms?

We said that there seemed to be two skills that distinguish synesthete-savants from nonsynesthetes: the ability to retain more numerical information in memory, including in working memory, and the enhanced speed of their ability to mentally compute very complex problems. Let’s look at whether the view that savants derive representations of photisms by an automatic routinized process of association handles these two abilities better than the inferential view and the representational proposal advanced here.

Performing mental computation of large numbers requires that a good deal of numerical information be retained in working memory, and working memory can only hold three to seven items at a time. As previously discussed, on the representational view, synesthete-savants can circumvent this problem because photisms provide a way to “chunk” and so store more numerical information. Mere association between photism and number, however, wouldn’t provide any advantage here. For the synesthete-savant to appreciate, much less solve a complex problem, numbers would still first have to be derived from photisms, leaving the synesthete with a working memory taxed to a level comparable to that of a neurotypical subject.

Moreover, the ability to retain more in working memory is necessary, but it is not sufficient to account for the relative difference in computational speed that we see between synesthete-savants and nonsynesthetes. To underscore this point, note that
synesthete-savants’ superior mental computation abilities are evident even in the computation of smaller numbers, such as in multiplying two two-digit numbers. In the representational view, vivid photisms carry information about a number’s complex set of relations to other numbers. But in the associative view, after numbers are derived from photisms, the performance of mental arithmetic is ultimately accomplished without photisms, in the same way as it is in neurotypical subjects. This view, therefore, does not offer a corresponding explanation for the synesthete-savants’ increased computational speed.

We will now consider a few additional objections to the view that some synesthetes represent numerical value in perceptual experience.

5 Objections

It has been argued that the view that photisms represent numbers in synesthete-savants has explanatory power and can account, better than alternatively views, for the relative abilities of synesthete-savants at mental arithmetic. But is this view vulnerable to any conclusive objections? In the remainder of this chapter, I want to consider potential objections to the argument presented.35

The first objection targets the assumption, required in our view, that the content of color experiences can consist of perceiver relative disjuncts, multiple types of properties including those that do not seem obviously visual (e.g., numerical values). When a neurotypical perceiver has a color experience that ascribes color quality \( q \), intuitively, he
or she represents that the perceptual object it is ascribed to has a particular spectral reflectance or color property. If the above argument is correct, then unlike neurotypical perceivers, the content of at least some synesthetes’ photisms is not exhausted by the color properties or spectral reflectance properties that they seem to ascribe. On our view, when the number-color synesthete has a color experience by which a digit is marked green, he or she visually represents the grapheme either to be green or representative of a particular number (or both). Our view, then, requires that visual experiences such as color experiences can have disjunctive contents, that they be capable of representing multiple properties, and that they be capable of representing different types of properties including those that may not be typically associated with color experience.

There is, however, a precedent for the view that a single qualitative experience can represent multiple types of properties, including properties that we do not ordinarily take to be associated with color experiences. Consider studies by Bach-y-Rita implementing the tactile visual substitution system (TVSS). The TVSS takes in visual information about light spectral reflectance through a camera positioned on the subject’s head and converts the information to a series of tactile pulses given on the subject’s skin. Subjects trained to interpret the information report experiencing the representations as primarily conveying information about objects located in the spatial field around the subject rather than as information about the objects that are causing the pulses on the skin. Moreover, several have noted that TVSS provides skilled users with information that is more like visual perception than tactile perception. Reports from blind
individuals concerning their experiences perceiving with the use of their walking canes are similar to the reports of TVSS users. They report representing space using a cane in a way that is similar to the way that sighted people do. The primary objects of perception seem to be objects arranged spatially around one. Blind individuals do not report the object causing sensations of pressure on their hand as the primary object of perception.

What is more, representations derived from TVSS are utilized to fill the same role in modulating behavior as visual representations play in sighted individuals. For example, TVSS users have learned to hit a ball with a bat and to perform assembly-line work. These are both activities that require that one react quickly to information about the way objects are positioned in space, information about properties that are typically the subject of visual representations rather than tactile. The reaction speed required for performing these actions suggests that the processing upon which it depends is automatic; that is to say that the representations utilized do not depend on a series of long and drawn-out translations. Automaticity of processing is often taken to indicate that a process is noninferential, or at least noninferential in the relevant way. The fact that processing is quick and noninferential suggests that these tactile representations already indicate spatially located objects. This would set a precedent for the view that a sensory quality such as a color experience or a tactile sensation can represent properties that are not typically associated with that modality.

The second objection that I want to consider here is that the view that synesthete-savants’ color experiences have disjunctive content may appear to yield counterintuitive
results for the accuracy of some synesthetes’ visual experiences. I have proposed that for a given synesthete-savant s, a blue photism may have disjunctive content specifying a color or number and that it represents the grapheme that it projects color onto as either blue and/or a number “4.” If s encounters an actual blue numeral “7,” but erroneously has a blue photism that projects blue onto the digit, then the color experience represents the digit as either a “4” or to be the color blue (or alternatively to have the property typically associated with blue). It may appear then that our view entails that in this case, s’s experience is veridical. Intuitively, however, it seems better to count s’s experience as misrepresenting the “4.” The fact that our proposal apparently does not make sense of the intuitively erroneous nature of the synesthete’s experience in such a case might be taken to count against our view.

It may be tempting to take the problem described above as motivating the view that synesthetes’ experiences have conjunctive instead of disjunctive contents. But this would not solve the problem either. In the conjunctive view, whenever a blue-four synesthete BF marks a blue body of water with a blue color quality, BF would thereby be misrepresenting the water to be blue and four. This result seems strange, though. Surely we want to say that a synesthete can veridically represent a colored object. The fact that we cannot appeal to conjunctive content appears to compound the problem for our view.

This objection problematically reads too much into the proposal that has been offered here. Our proposal about the disjunctive nature of the content of at least some synesthetes’ photisms can be implemented in two ways. One view is that each time a
synesthete tokens a color experience \(t\), \(t\) itself has the disjunctive content that the object it projects its color quality onto is either a particular color \(c\) or representative of a numerical value \(n\) (or both). This interpretation could yield the unhappy result discussed above. The alternative view is that color experiences have disjunctive content for a synesthete \(s\) such that whenever \(s\)’s experience instantiates a color quality \(q\), \(q\) will either represent that the item is a particular color or that it has a particular numerical value, or \(q\) will represent that the item is a particular color and that it has some numerical value. This alternative interpretation does not incur the problems raised above. I have been careful to stay neutral with respect to which of these two versions of the view best describes the synesthete-savant. To the extent that one finds the objection above compelling, he or she may find it better to understand the proposal about the disjunctive content of synesthetic experiences in this latter way.

**Conclusion**

In recent years there has been a lot of work devoted to better understanding the nature and scope of perceptual representation. Conservatives have argued that perceptual experiences can only represent properties such as colors, shapes, and their respective relations. It was argued here that perceptual experiences can, and in some cases do, represent numerical values.\(^3\) If photisms play the role of facilitating mental calculation that synesthete-savants claim they do, then it seems that the best explanation for this will be that synesthetes’ color experiences, or “photisms,” represent numerical values.
Moreover, insofar as such synesthetes’ photisms project their colors onto digits, their experiences should represent the digits that color is projected onto as having the properties that photisms represent. The visual experiences of the synesthete-savant therefore represent the digits that color qualities are projected onto as having numerical values.40

Figure 7.1

Notes

1. 1934, 122.

2. Recent arguments for the view that conscious experiences have representational content are given by Pautz (2010), Searle (1983, 1992), Siegel (2005, 2010), and Siewert (1998).

3. People accept the view that perceptual experiences have representational content for a variety of reasons. Some are persuaded of the thesis based on the “transparent” character of perceptual experience (e.g., see Horgan & Tienson, 2002; Tye, 1995, 30; c.f. also Tye, 2000). Moreover, the commonsense view is that conscious perceptual experiences, like beliefs, may be either veridical or nonveridical. This is made sense of by the view that experiences have content, since content is taken to be equivalent to the conditions under
which the experience would turn out to be veridical (Siewert, 1998). Finally, this view fits well with the common intuition that some beliefs are directly justified based on what is presented via the “testimony of the senses.” Intuitively, when I am standing in front of, for example, an ocean, I seem to be justified in a direct and immediate way in my belief that the world is a particular way based on what I see (Sellars, 1997; Brewer, 1999).


5. We can make a distinction between what we represent in the content of perceptual experience, and what we go on to believe based on those experiences. Tye and Dretske both hold that belief or judgment-independent visual experiences cannot represent high-level properties. For Dretske (1995), nonepistemic experiences are automatic, modular, sensory representations of objects that are impervious to beliefs or learning. To see an object as a particular kind of thing requires forming a judgment or belief about the object. Tye (1995) draws a sharp distinction between sensory/perceptual representations, which are modular, and the cognitive states that they feed into, such as beliefs and other conceptual states or “thoughts.” Unlike thoughts, perceptual states are thought to be nondoxastic and nonconceptual.

6. Crutchfield (2012); Siewert (1998). That number-color synesthetes represent objects to have semantic value should be of interest to philosophers of perception who are interested in the nature and content of perceptual experience as well as what those
experiences represent. But the issue has significance for other philosophical projects as well. For instance, Siegel (2005) discusses the relevance for projects in epistemology concerning the justification of beliefs such as which beliefs are directly versus indirectly justified and what other mechanisms and considerations justification might depend on. Moreover, Bayne (2011) notes that whether or not we can represent high-level properties in perceptual character may also bear on the metaphysical problem of determining whether and how something seemingly immaterial like consciousness can be accounted for in material terms. Not all reductive theories of consciousness are compatible with the representation of semantic value. For additional discussion see Macpherson (2011).


12. For a thorough discussion of both the scientific and philosophical literature on synesthesia, see Hermanson and Matey (2011).
13. Some work with a broader definition of synesthesia on which synesthetic experience can include systematic, nonmodal correspondences such as the assignment of genders to numbers.


16. Ramachandran and Hubbard (2001). Dixon et al. (2000) have studied an individual with higher synesthesia who has color photisms not merely when viewing visual items that have recognizable cognitive significance, but also when merely considering the numerical concept.

17. By “photism” I mean the unusual color experience typical of number-color synesthetes. There is reason to take the photisms of some synesthetes to be representational rather than as mere unintentional color qualia. Some synesthetes’ photisms have transparent- or world-presenting character, and transparency has been used as evidence of representation (Horgan & Tienson, 2002; Tye, 1995, 2000). For instance, Dixon, Smilek, and Merikle (2004) demonstrate that so-called “projector” synesthetes’ experiences present the world as if the external grapheme that triggers a photism has the color property of that photism. This is reinforced by the fact that when target graphemes that are associated by the synesthete with a particular color are presented as flanked by formally similar graphemes, the target tends to “pop out” saliently when the color of its
flankers is incongruent with the color that the synesthete projects onto the significant grapheme. A cluster of such graphemes may form a salient group such as a triangle (Ramachandran V.S & Hubbard E.M., 2001. Cytowic (1993) also discusses projector synesthesia.

18. Although I focus on Tammet, there are numerous other synesthetes who claim to have savant abilities in virtue of their synesthesia. For instance, Jason Padgett experiences complex fractal images upon seeing many everyday objects and spontaneously understands the mathematical equations that the fractals are based on. For discussion, see Brogaard (2011). Baron-Cohen et al. (2007) suggest that having synesthesia may increase the likelihood for savantism. They note the established link between savantism and autism spectrum conditions and make the case that the co-occurrence of synesthesia along with autism spectrum conditions may increase the likelihood for savantism.


20. Baron-Cohen et al. (2007). This means that photisms he experiences as correlating with numbers that are similar (i.e., 99 and 999) have systematically similar features and number-to-photism pairings are the same over multiple testings. In research on synesthesia, this systematicity and consistency are taken as indicators that photisms are perceptually real and not merely associated ideas.

22. Miller (1956) argued that the capacity of working memory was for roughly seven items, but many psychologists have since argued that the accurate number is more likely to be three to five items.


25. Ibid., 141).

26. The working memory component that stores verbally encoded information is called the “phonological loop” (Baddeley A.D. and Hitch G.J., 1974). The importance of the phonological loop in mental arithmetic for retaining information about the problem and partial results while the problem is solved is addressed by both Ashcraft (1995) and Heathcote (1994). Further evidence of the role of the phonological loop in mental arithmetic comes from Fuerst and Hitch’s (2000) studies in which subjects were exposed to repeated vocalization of a word while engaged in mental arithmetic. They found that when participants were required to retain problem information in working memory, the concurrent articulator suppression, which researchers take as loading the phonological loop, interferes with mental arithmetic. When subjects were allowed visual access to the problem, the interference ceased.
27. The storage component responsible for retaining visually encoded information is called the “visuospatial sketchpad” (Baddeley A.D. and Hitch G.J., 1974). For discussion of the role of the visuospatial sketchpad in mental arithmetic, see Logie, Gilhooly, and Wynn (1994) and Ashcraft (1995). Hope and Sherrill (1987) note that many engage in finger writing when performing mental arithmetic, indicating the role of visual images in mental calculation, particularly in retaining positional information about numbers in columns and information about carrying operations. Some studies show performance in arithmetic to be impaired when subjects are given a task involving spatial or visual information to perform concurrently.

28. Chincotta et al., 1999; Zago et al. (2001) make the stronger claim that mental calculation relies exclusively on visuospatial information and not verbally encoded information. They used Positron emission tomography (PET) to arbitrate between models of mental calculation that emphasize linguistic or visuospatial representation. Their findings implicate visuospatial representation in both arithmetical fact retrieval and actual calculation.


33. Tammet’s reports seem consistent with the view that to entertain a numerical concept is to have a representation that plays such roles. He writes, “Using the example of 6,253 from the multiplication we just looked at, I can immediately ‘see’ that its shape derives from the combination of $13 \times 13 (169) \times 37$. I factorize larger numbers (above 10,000) by separating them into meaningful (visualizable) related parts: for a number like 84,187, I separate it into 841 ($29 \times 29$) and 87 ($2903 \times 29$), telling me immediately that the number is divisible by 29 as well as 2,903, a prime” (Tammet, 2009, 142–143).

34. See also Brogaard (2011).

35. Additional objections are addressed in Matey (2013).

36. Some question whether synesthetic experiences really are phenomenally like regular color experiences. Macpherson (2007) notes that some synesthetes can identify both the color quality synesthetes project onto a significant digit (say, blue) as well as the actual color that the digit is printed in (say, black). For further discussion of Macpherson’s view as well as a critical response, see Hermanson and Matey (2011).


39. It is one thing to ask what properties perceptual experiences are capable of representing and another to ask what properties they do represent. For some discussion of this distinction, see Macpherson (2011). My aim here is to focus on the first question about what properties can be represented in perception by arguing that in at least some cases, numerical values are represented. The discussion, however, should not be taken as irrelevant to the question about what properties perceptual experiences more commonly represent. For the relevance of considerations such as those presented here and what is more typically represented, see Matey (forthcoming).

40. One might now wonder whether there is any reason to think that claims about the representational nature of the visual experiences of synesthetes can generalize to speak about the representational capacities of visual experiences I believe that the answer here is yes. Recent work suggests that we can draw general conclusions like this about representation by studying visual representations for synesthetes.

References


capacity visuo-spatial storage system. *Quarterly Journal of Experimental Psychology, 52A*, 325–351.</p>


