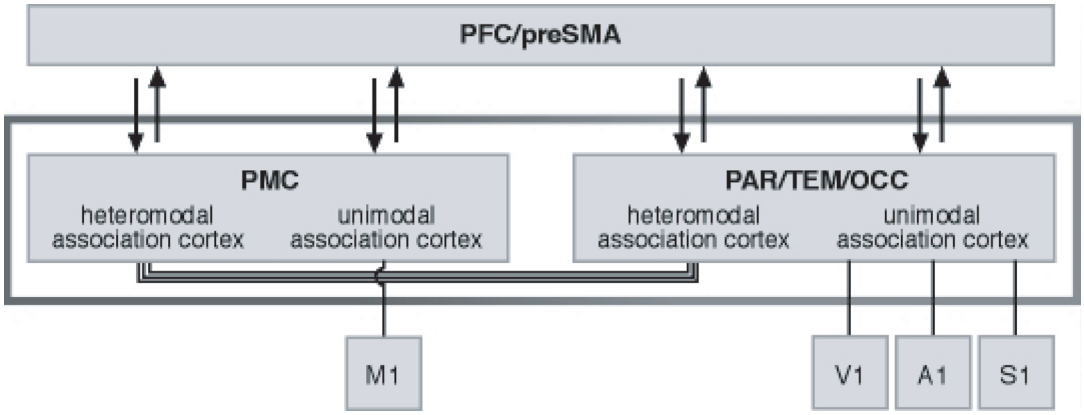


Figure 1 (Schubotz & von Cramon). Suggestion for a simplified neural implementation of a multipurpose emulator system (note that inverse models and/or Kalman filters might be added by cortico-ponto-cerebellar loops). Abbreviations: PFC, prefrontal cortex; PAR/TEM/OCC, parietal, temporal, occipital cortex; M1, primary motor cortex; V1/A1/S1, primary visual/auditory/somatosensory cortex, respectively.

the unimodal components of the general-purpose emulator. Grush correctly reminds us that "the emulator is a neural system: any and all of its relevant states can be directly tapped" (target article, sect. 5.1, para. 5).

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NOTES

1. Furthermore, redundancy emerges in an account that proposes one type of imagery (modal) to spring alternatively from two types of emulators (modal and amodal), but also two types of imagery (modal and amodal) to spring from one emulator (amodal).

2. Grush's pilot-without-flight-simulator metaphor (sect. 3.1) exemplifies the necessity of measurement, but it also expresses how the measurement assumption suggests the introduction of little monolingual homunculi: A Turkish-speaking controller and a French-speaking emulator need a translation – the extra measurement.

Emulator as body schema

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Abstract: Grush's emulator model appears to be consistent with the idea of a body schema, that is, a detailed mental representation of the body, its structure, and movement in relation to the environment. If the emulator is equivalent to a body schema, then the next step will be to specify how the emulator accounts for neuropsychological and developmental phenomena that have long been hypothesized to involve the body schema.

Grush offers a detailed model of an information processing system that is hypothesized to represent the body as it moves in relation to the environment. His model of a body emulator appears to be consistent with the long-held notion of a "body schema." The term "body schema" was introduced nearly 100 years ago in the neuropsychological literature as a unifying construct relating a number of disorders that seemed to indicate disturbances in the way patients perceived or conceived of their bodies (reviewed in Poeck & Orgass 1971). One syndrome that was originally cited as a disorder of the body schema was the phantom limb, which Grush explicitly mentions as explainable in terms of the operation of his hypothesized body emulator. This suggests that, at least in some instances, the emulator and the body schema are equivalent.

The body schema was conceived as a dynamic representation of one's own body, whose operation was most noticeable in cases of dysfunction (like phantom limbs) but whose normal functioning was thought to include a range of motor and cognitive phenomena from postural control to bodily self-concept. However, since the term was introduced, the notion of a body schema has become increasingly vague and overinclusive rather than more precise, and now there is genuine confusion over what a body schema is supposed to be and how it differs from a body image, body percept, body concept, or body awareness (for discussions, see Gallagher & Meltzoff 1996; Poeck & Orgass 1971; Reed 2002b).

Perhaps Grush's emulator can bring some order to this confused state of affairs. He proposes that the emulator is a cognitive structure that represents the body as it moves and acts within the environment. This is at least part of what a body schema is supposed to be, and Grush's model provides precise detail about how it may be instantiated. If the emulator and the body schema can be equated, this would represent a useful step forward because it can provide the field with a new and more precise definition of body schema, that is, a mental representation of the body that "implements the same (or very close) input-output function as the plant" (sect. 2.2), where the plant is the body being represented and controlled by the emulator mechanism.

Grush discusses how his emulator model can account for a number of low- and high-level cognitive phenomena, from motor control and motor imagery to simulation of another's mental states. If we go ahead and equate the body schema with the emulator, then the model will also have to account for the neuropsychological phenomena that led investigators to postulate a body schema in the first place.

One of those is the phantom-limb phenomenon, which Grush addresses when he suggests that the existence of separate groups of phantom-limb patients who can and cannot move their phantoms can be explained by the amount of time the emulator experienced limb paralysis prior to amputation. This is a neat explanation. However, there are also reported cases of phantom limbs in congenital limb deletions (Poeck 1964; Weinstein & Sersen 1961) which are admittedly very rare but may pose a problem for the emulator model. Another neuropsychological disorder relevant to bodily motion and perception that the emulator should address is hemi-neglect, whereby the patient ignores perceptual information from one side of his visual field and as a result may stop using and lose a sense of ownership for his body parts on the affected side. Ideomotor apraxia is another classic disorder of the body

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schema, defined as the inability to imitate gestures, which the emulator as body schema would have to explain.

Owing to imprecision in the way the term "body schema" was introduced, other disorders that have very different characters have traditionally also been classified as disturbances of the body schema. These include autotopagnosia (also called somatotopagnosia), whereby the patient becomes unable to recognize, localize, or name specific body parts, finger agnosia, whereby the patient is unable to recognize or name his fingers, and right-left disorientation, whereby the patient has difficulty identifying body parts as being located on the right or left side of their bodies.

Perhaps equating the body schema with the emulator will clarify the extent to which so-called disturbances of the body schema should be classified together. As several authors have already noted, phantom limbs and autotopagnosia are similar only insofar as they have something to do with the body; one is likely to be a low-level perceptual-motor dysfunction, whereas the other is a form of aphasia. If the emulator is equivalent to a body schema, then those disorders that do not implicate the specific cognitive machinery hypothesized to run the emulator can be reclassified, thereby bringing some order to an historically difficult-to-classify set of phenomena.

It should be noted that disorders of the body schema typically result from brain damage to the cortex, often the parietal lobes (Reed 2002b), but Grush hypothesizes that the emulator is located in the cerebellum (sect. 3.4).

The notion of a body schema most often appears in the literature on neuropsychological disorders, but it has also been proposed as the neurocognitive basis for neonatal imitation (Gallagher & Meltzoff 1996), whereby newborn infants match the bodily movements of adult modellers (usually facial movements but imitation of finger movements has also been reported; Meltzoff & Moore 1977). If the emulator is a body schema, can it account for neonatal imitation?

The emulator model that Grush presents is attractive because it is so precise, in stark contrast to the notoriously vague, ill-defined notion of a body schema. Although the emulator as presented cannot yet account for phenomena thought to implicate the body schema, there appears to be potential for the emulator model to bring some order to the neurological and developmental phenomena that have traditionally been thought to involve a body schema.

Evidence for the online operation of imagery: Visual imagery modulates motor production in drawing

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Abstract: One property of the emulator framework presented by Grush is that imagery operates off-line. Contrary to this viewpoint, we present evidence showing that mental rotation of a simple figure modulates low-level features of drawing articulation. This effect is dependent upon the type of rotation, suggesting a more integrative online role for imagery than proposed by the target article.

Grush provides evidence for how imagery allows the individual to model the outcome of a particular action. This would necessarily operate off-line so that imagined movements are not carried out. Yet, if mental imagery is performed off-line, then a movement that results from this imagery system should be executed in the same manner as a movement made without being preceded by imagery. Preliminary data from our laboratory counter this viewpoint and suggest that mental imagery can actively (and unconsciously) modulate movement in a manner that is not predicted by the emulation theory of representation.

Models of drawing (Guérin et al. 1999; van Galen 1980; van Sommers 1984; 1989) typically assume the distinction between cognitive aspects of drawing and simple motor-output procedures. For example, the van Sommers (1989) model identifies a specified stage in the drawing process which controls the motoric components of the drawing procedure as a function of the constraints of both the movements involved and the materials used. For example, right-handers show a particularly strong tendency to begin their drawings at the top left of the figure. This bias is a highly robust feature of drawing production (Goodnow & Levine 1973; van Sommers 1984; Vinter 1994). Along with other graphic production rules (e.g., pen lifts), starting position is determined to optimise drawing efficiency in light of movement restrictions (Thomassen & Tibosch 1991). As such, they should not be affected by the nature of the more central cognitive processes that precede them.

To test the extent to which imagery occurs off-line, and prior to graphic production rules, we compared simple figure copying with production of the same figure following a mental rotation. The graphic output is identical in both conditions, but the preceding cognitive processes differ. As a result, any difference in drawing articulation between conditions must be due to an online influence from imagery. Participants copied right-angled triangles, which are known to have a highly stereotypical starting position (van Sommers 1984). On each trial we recorded the vertex at which participants began drawing.

In Experiment 1, participants (N = 24) were presented with sheets of A5 (210 x 148 mm) paper on which was printed a single right-angled triangle in the centre of the upper portion of the page. Stimuli measured 2 cm in height and width, and could be at one of eight orientations (after van Sommers 1984). Participants were required to mentally rotate the figure either 90° clockwise or 90° anticlockwise. They then drew the product of their mental manipulation below the original figure. Starting positions were compared with those in a copy condition for the same triangles. Participants began at a vertex that was consistent with a *motor* response (i.e., starting at the same vertex as when producing the same figure in the copying condition), an *imagery* response (i.e., starting at the same vertex as when copying a pre-rotated version), or *neither* type of response.

Start-point frequency data were transformed into log-odds ratios (see Wickens 1993) and analysed using one-sample *t*-tests. There was a significantly greater number of *motor* responses than *imagery* responses ($t = 13.9$, df = 23; $p < .0001$). More crucially however, there was a significantly greater number of *imagery* responses than *neither* responses ($t = 4.04$, df = 23; $p < .001$). This shows a reliable effect of mental rotation on starting position: starting position was rotated with the triangle. In addition, participants showed the same number of pen lifts for the copy and rotation conditions, and comparable error rates.

Starting position was not completely subject to low-level peripheral factors (subsequent to imagery). Instead it seems to be determined prior to, or during, the manipulation of the image. This argues against a strictly serial account of drawing production (van Sommers 1989) and also suggests that mental imagery is not as off-line as the emulation theory proposes. As Grush points out in the target article, there is increasing evidence to suggest that image manipulation is intrinsically linked to the motor system, even when simply planning a rotational movement (Wohlschläger 2001). It also seems to be the case that the way the mental rotation is conceptualised affects the likelihood of motor structures being used to support the manipulation (Kosslyn et al. 2001). Wraga and colleagues (2002) found that when participants imagined rotating a stimulus there was activation of primary motor cortex, but when they imagined themselves rotating around a stationary stimulus there was no motor activation.

Following on from this, in Experiment 2, participants were asked to imagine *themselves* moving around the page to view the triangle from the point denoted by an arrow marker (i.e., with the arrow pointing to what is now the bottom of the stimulus). When

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