

## Journal Club

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## Advantages of Using the Dorsolateral versus the Dorsomedial Visual Stream for Decoding Hand Movements

Guy Rens

Motor Control Laboratory, Movement Control and Neuroplasticity Research Group, Department of Kinesiology, Group Biomedical Sciences, KU Leuven, B-3001, Belgium

Review of Filippini et al.

Cognitive neural prosthetics (CNP) open promising avenues for assisting patients who have limited sensorimotor function and cannot skillfully interact with their environment. CNPs consist of brain-implanted electrodes, signal decoding algorithms, and an external assistive device that is controlled by the processed signals. In theory, the primary motor cortex (M1) is an ideal brain area for decoding neural signals related to hand-object interactions (e.g., grasping), given its role in controlling hand movements. Unfortunately, decoding of object-specific hand movements in M1 requires the processing of neural activity underlying multiple fractionated movements as grasping unfolds during movement execution in different arm and hand M1 sectors (Velliste et al., 2008). To bypass this issue, CNPs are aimed to decoding cortical activity related to cognitive function rather than to strictly motor execution per se. For example, when a patient wants to drink, the CNP only requires the individual's intention (i.e., drinking) for transforming these signals

into an adequate motor response (e.g., bringing a glass to the mouth). For these reasons, it is sensible to decode skilled hand-object interactions from brain areas located upstream to M1, such as parietal and premotor regions, which store object visual representations and encode global grasp-specific motor commands (Andersen et al., 2010; Davare et al., 2011).

Filippini et al. (2017) hypothesized that the visuomotor medial posterior parietal area (V6A) might be a particularly promising region for decoding of grasping, given that V6A contains both visual and somatosensory neurons and is involved in controlling both arm and eye movements (Galletti et al., 2003). The authors used two *Macaca fascicularis* monkeys that were trained to perform an instructed-delay grasping task either in light or dark conditions. Task execution was divided into three distinct phases: object presentation, delay period (a planning phase), and movement execution. Five different objects were used, all requiring a unique type of grasp. For both light and dark conditions, monkeys briefly viewed the object during the presentation phase. Subsequently, the planning and execution phases were executed under full visual guidance or in darkness, depending on the condition (for details, see Filippini et al., 2017, their Fig. 1). Microelectrodes were used to record neural activity in V6A while monkeys performed the task. After the experiment, a naive Bayesian classifier

was used for decoding neural signals. This classifier was trained to assign trials to an object/grip condition based on the decoded neural activity. After being trained on 80% of the trials, the classifier assigned the remaining trials to the different object/grip conditions. To test the classifier's accuracy, Filippini et al. (2017) investigated whether the assigned condition of each trial matched the actual condition of the respective trial.

When the classifier was trained on the delay period, it achieved very high accuracy in assigning decoded neural activity of the remaining samples of the same task phase to the correct object/grip condition. These findings were very similar for the execution phase. For the object presentation phase, while the classifier still achieved good accuracy levels, its performance was considerably worse compared with the delay and execution phases (Filippini et al., 2017, their Fig. 3). This is likely due to using the whole presentation phase for signal decoding. Indeed, Aflalo et al. (2015) reported that neural activation in the posterior parietal cortex can be interpreted only 190 ms after target presentation. In addition, Filippini et al. (2017) investigated whether the classifier's ability to assign neural activity to the correct object/grip conditions changed over time. In line with findings from Aflalo et al. (2015), accuracy levels were very low just after object presentation. However, accuracy greatly improved

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Correspondence should be addressed to Dr. Guy Rens, Departement Bewegingswetenschappen, KU Leuven, Tervuursevest 101, B-3001, Heverlee, Belgium. E-mail: [Guy.Rens@kuleuven.be](mailto:Guy.Rens@kuleuven.be).

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over time during the presentation phase, plateaued during the delay period, and increased again just before movement onset (Filippini et al., 2017, their Fig. 4).

Finally, Filippini et al. (2017) investigated whether neural encoding of grasping in V6A was similar over the different phases of the task. As such, the classifier was trained on one phase and then tested on the other task phases. When the classifier was trained on the presentation phase, it was able to assign samples to the correct condition with high accuracy when tested on the delay period, but not on the execution phase. Conversely, training the classifier on the grasp execution phase resulted in a low assigning accuracy when tested on the object presentation phase. Interestingly, training the classifier on the object presentation phase resulted in a higher accuracy for all but the last epoch of the delay period, compared with the classifier trained on the execution period (Filippini et al., 2017, their Fig. 5). This difference is likely caused by an alteration in neural encoding occurring at the end of the delay period. Overall, these results indicate that object types can be decoded from V6A with high accuracy but that it is important to keep in mind the limited transferability of training and testing the classifier on the different phases of the task.

It is well established that V6A is primarily involved in controlling reaching and wrist orientation (Fattori et al., 2017). The ventral part of V6A (V6Av) receives strong projections from the medial superior temporal area and other parietal areas, such as the medial parietal area and the medial intraparietal area. These areas are primarily involved in visual motion detection and in visually guided reaching (Tanaka and Saito, 1989; Grefkes and Fink, 2005). Therefore, it has been proposed that V6Av is part of the dorsomedial visual stream, defined as a parietofrontal pathway processing visuospatial information for encoding reaching movements toward objects (Galletti and Fattori, 2017). V6Av is reciprocally connected with the dorsal part of V6A (V6Ad), which also receives projections from areas of the intraparietal sulcus that process object features related to actions, and from the inferior parietal lobule, which is important for spatial orientation and object recognition (Andersen, 2011; Grefkes and Fink, 2005). Interestingly, V6Ad contains a substantial number of somatosensory neurons, which mainly represent the upper arm. For these reasons, it has been suggested that V6Ad is a visuomotor area, combining visual and somatosensory information to predict pro-

prioceptive sensory feedback for grasping. Although V6Ad does not directly project to M1, it is reciprocally connected with dorsal premotor areas F2 and F7, which are, respectively, involved in the guidance of reaching and in learning of new visuomotor associations.

It is noteworthy that another strong candidate for driving CNPs is the anterior intraparietal area (AIP), which is part of the dorsolateral visual stream, defined as a parietofrontal pathway processing visual object properties for encoding grasping movements (Galletti and Fattori, 2017). This area has major connections with all the aforementioned dorsal parietal areas and several areas of the inferotemporal cortex, belonging to the ventral stream (Grefkes and Fink, 2005; Grafton, 2010; Kravitz et al., 2013). Interestingly, inferotemporal cortex is crucial for recognizing and encoding complex object features, thus mediating information about object identity. This suggests that, in contrast to V6Av, AIP not only receives inputs from the dorsomedial visual stream but also from the ventral visual stream. Furthermore, a large majority of neurons in AIP are responsive to simple visual stimuli (e.g., different geometrical shapes) even when grasping is not planned, whereas only a minority of neurons in V6A are responsive to these stimuli (Galletti and Fattori, 2017). This suggests that AIP is not only involved in controlling grasp execution but also in object recognition. Finally, similar to V6Ad, AIP is not directly connected with M1 but is reciprocally connected with ventral premotor area F5, which is involved in hand shaping during grasping (Matelli et al., 1986; Davare et al., 2010; Galletti and Fattori, 2017).

Although Filippini et al. (2017) showed that V6A can be used to accurately decode grasping, it appears that both V6A and AIP fulfill complementary roles during such tasks: it is likely that V6A first defines a global motor command that is suitable to reach and preshape the hand toward the object. This initial motor command is then tailored by AIP, which further specifies appropriate digit contacts based on object identity information provided by the ventral stream. This suggestion is supported by studies showing that lesioning V6A or AIP causes misreaching or deficits in hand shaping, respectively (Battaglini et al., 2002; Davare et al., 2007). However, considering the different anatomical connectivity profiles of V6A and AIP, it seems plausible that AIP is a more suitable target for decoding grasp, given that it has immediate access to visuospatial informa-

tion about the object from dorsomedial areas and cognitive information about the object identity from ventral stream areas.

Given that V6A primarily plays a role in goal-directed reaching, how can grasping be decoded from this region? One could find an explanation in the underlying components of the experiment performed by Filippini et al. (2017). The authors mention that the monkeys were overtrained to grasp the different objects. It is widely thought that area F7, reciprocally connected with V6A, is involved in learning visuomotor associations. Therefore, it is possible that visual information provided by V6A primed F7 to retrieve the well-learned object/grasp associations, which in turn modulated V6A activity based on combined visual and somatosensory feedback prediction. A second explanation is related to the functional connectivity between V6A and AIP. If both areas monitor interdependent sequences of actions, such as reaching followed by grasping, it is crucial that the areas interact with each other. For example, when reaching out to drink from a cup, it is crucial that the reaching movement enables the hand to grasp the cup by the handle, independently of the cup orientation. As such, it seems evident that V6A needs to have access to the final hand shaping to plan the reaching movement components accordingly. For this reason, it is plausible that grasp specificity in V6A is strongly modulated by the reciprocal connection with AIP.

In conclusion, the study of Filippini et al. (2017) highlights the potential value of V6A for decoding grasping. However, due to important functional interactions between AIP and V6A during reach-to-grasp movements, grasp decoding in V6A might be primarily driven by AIP. Therefore, although CNPs could greatly benefit from simultaneously sourcing neural signals from both V6A and AIP, merely recording from AIP may provide enough information to drive CNPs with high accuracy.

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