



Editorial

Temporal resolution in swallowing neural control: The way forward

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Investigation of the neurophysiologic control of swallowing presents the researcher with a fascinating and challenging journey through the varied terrains of neuromotor control. A unique task by virtue of its complexity, the swallowing process is engaged both volitionally and reflexively, presumably driven by both cortical and subcortical neural structures, and is complicated by the nature of swallowing which is frustratingly inconsistent across such contexts as arousal, attention, diet level and task.

Early researchers have extensively defined the imperative role of brainstem central pattern generators in the creation of the hard-wired swallowing motor plan (Miller, 1982; Jean, 1984, 2001), perhaps almost to the exclusion of recognition of cortical involvement. The pendulum has perhaps now swung too far in the other direction. More recent trends in swallowing research have heavily emphasised *in situ* cortical activation during swallowing using brain imaging techniques. Studies utilizing functional magnetic resonance imaging (fMRI) have revealed that many regions of the cortex are activated during the swallowing process, with major contributions from the primary motor and somatosensory cortices, the supplementary motor area (SMA), cingulate gyrus and anterior insula (Mosier et al., 1999a,b; Hamdy et al. 1999; Kern et al., 2001; Martin et al., 2001, 2007; Mosier and Bereznaya, 2001). Increased activations at these sites are generally reported to be bilateral, with hemispheric dominance evident in most studies. Which hemisphere is 'swallowing dominant' remains unclear from studies to date (Hamdy et al., 1999; Mosier et al., 1999a,b; Martin et al., 2007), with implications that task, gender or individual variation may contribute hemispheric dominance.

But even with many skilled researchers developing creative paradigms to tease out cortical contributions, this research is fraught with difficulty and to date has been confined to evaluation of the entire complex swallowing process, thereby yielding spastically precise but functionally non-specific information regarding cortical localisation. With the pharyngeal swallow contained in a temporal envelope of approximately 800–1200 ms, and significant movement artifact generated by lingual and pharyngeal muscular structures, the temporal resolution of fMRI struggles to capture the intricacies of swallowing neural control.

Nonaka et al. (2009) are to be lauded for their contribution to the task of dissecting the neural substrates of specific temporal components of swallowing. By evaluating only *pre-motor* brain activity, very specific information regarding neural control for motor planning can be harvested with precise temporal specificity and with management of extra-cranial lingual artifact that has plagued

other research. This novel approach promises to clarify our understanding of cortical contribution to swallowing and evaluate potential "encephalisation" as a mechanism of neural recovery.

This is not the first research of this type. Recently, researchers have looked at an event-related potential called the Bereitschaftspotential (BP) that provides similar information to contingent negative variation (CNV) regarding pre-motor planning. The literature investigating the BP related to swallowing remains sparse (Hiraoka, 2004; Huckabee et al., 2003; Satow et al., 2003). However, all of these studies found that volitional swallows were preceded by a BP, suggesting a contribution from the SMA to pre-motor planning.

The proposed contribution of SMA activation prior to volitional swallowing varies according to these researchers. The pre-motor planning seen in swallowing could represent the oral preparatory stage, as it mimics the BP seen for tongue protrusion (Satow et al., 2003). Lingual myogenic artifact may contribute to such observations and consequently requires rigorous control to ensure it does not contaminate electroencephalographic (EEG) recordings. When interference of lingual movement was controlled by Huckabee et al. (2003), the swallowing task generated a BP of smaller amplitude and latency than a finger tapping task. This finding was unexpected given the possible influences on the BP amplitude; that is, swallowing involving sequential, more complex movement of a proximal part of the body. Both of these studies allude to a possible 'redirection' of the neural command to a subcortical structure for innervation of swallowing musculature. Satow and colleagues (2003) identified that post-movement potentials related to swallowing are smaller than those related to tongue protrusion, despite greater muscle activation, suggesting reduced engagement of M1. Similarly, in the Huckabee et al. study (2003) volitional swallowing recruited no identifiable 'late BP' component and post-movement potentials in swallowing were considerably smaller than finger movement. As the second component of BP is known to represent transfer to the primary motor cortex, this appears to support an altered motor pathway when compared to other volitional motor tasks.

Hiraoka (2004) suggests that sensory issues may account for SMA contribution to swallowing, suggesting saliva swallows require more motor planning than bolus swallows due to less sensory feedback. Another explanation that fits with the fundamentals of SMA activation prior to motor activity is the level of volition involved in each task. The amount of volition required for saliva swallows is substantial, given the lack of reactive need to protect the airway. Therefore, the BP associated with such a task would presumably

be of greater amplitude than that involving more automatic components generated by an external stimulus, such as water.

In this issue, the research by Nonaka et al. (2009) extends prior research by evaluating components of volition and preparation as they influence swallowing behaviour. By evaluating a ‘cousin’ of the Bereitschaftspotential—the contingent negative variation—they specifically address the changes in cortical activation with ‘cued’ swallowing. Anecdotal reports have suggested that verbal cue to swallow may increase oral transit time and produce “apraxia of swallowing” in patients with a left hemispheric stroke (Logemann, 1998; Robbins and Levin, 1988; Robbins et al., 1993). This was recently challenged in research by Daniels et al. (2007) who identified that a cue to swallow decreased, rather than increased oral transit time” and stage transit duration.

The newly offered data by Nonaka et al. (2009) in this journal documents greater cortical activation with cued swallowing. However, they interpret these data to suggest that “...the consciousness on the act of swallowing itself is important for patients with dysphagia to carry out safe swallowing.” (p. ##). This interpretation bears reconsideration by these researchers and those who will follow. Mistry and colleagues, in studies using repetitive transcranial magnetic stimulation (rTMS) of the primary motor cortex, document that producing a ‘virtual lesion’ of the motor strip results in more rapid onset of swallowing in healthy controls. These researchers argue that “Our data imply that the motor cortex may have a significant inhibitory role in regulating swallowing behaviour at the level of the brainstem and supports the notion that unilateral brain injury disrupts swallowing because of its lateralized properties.” (Mistry et al., 2007, p. 536).

Regardless of interpretation, it is careful research such as that offered in this journal that will help to pave the pathway of our understanding of swallowing neural control. The use of electrophysiologic methods allows for greater temporal specificity, which is key to understanding the dynamic neurophysiologic underpinnings of individual components of swallowing control. Future research may benefit maximally from the emerging technologies which merge the temporal specificity of EEG with the spatial sensitivity of fMRI (Laufs et al., 2008).

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