Journal Club

Editor's Note: These short, critical reviews of recent papers in the *Journal*, written exclusively by graduate students or postdoctoral fellows, are intended to summarize the important findings of the paper and provide additional insight and commentary. For more information on the format and purpose of the Journal Club, please see http://www.jneurosci.org/misc/ifa_features.shtml.

Is Action-Perception Coupling Improved with Delay in Patients with Focal Cerebellar Lesions?

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Review of Christensen et al.

It has been proposed that the cerebellum uses internal forward models to predict sensory consequences of particular actions (Wolpert and Flanagan, 2001). This allows movements to be corrected when necessary. In addition to its paramount role in the control of movements, the cerebellum is also involved in sensory processing and perception, but there is no straightforward evidence for the cerebellum's involvement in the integration of action and perception. Therefore, a recent study in *The Journal of Neuroscience* set out to investigate the role of the cerebellum in action–perception coupling. Specifically, Christensen et al. (2014) studied patients with focal cerebellar lesions and healthy controls in a paradigm that measures the effect of motor execution on visual action perception.

Participants performed waving motions with the right arm using a setup that allowed participants' own arm movements to be visually presented on a screen in front of them (as five black dots). These stimuli were accompanied by varying numbers of noise dots, which moved based on the waving movements of the participants, but were spatiotemporally scrambled. The patients were asked to indicate whether they recognized a waving arm movement. Two-thirds of the trials contained the arm and noise dots, and in half of these trials the participants' own movements were presented in real-time ("synchronous" test condition; delay ~38 ms), while in the other half the participants' movements were presented with a time delay of 700 ms ("asynchronous" test condition). In the remainder of the trials, only noise dots were presented. In addition, the participants performed the waving arm detection task without performing the waving movements (baseline condition).

Detection performance was assessed using the noise tolerance value (NTV; i.e., the maximum number of noise dots that would lead to 75% of the optimal detection sensitivity). The influence of motor execution on detection performance was quantified (for the synchronous and asynchronous conditions separately) as the logarithm of the NTV of the test condition divided by the NTV of the baseline. This measure was called the interaction-index. An interaction-index value >0 indicates a facilitatory effect of motor execution on perception, whereas a value <0 indicates an inhibitory effect. The interaction-indices of the synchronous and asynchronous conditions were combined in one overall measure of action–perception coupling (APC-index), in which the interaction-index of the asynchronous condition was subtracted from the interaction-index of the synchronous condition.

In healthy participants, motor execution facilitated action perception performance in synchronous conditions, but inhibited action perception performance in asynchronous conditions. The APC-index for this "normal" action–perception coupling was positive. Importantly, no interaction was observed in the cerebellar patient group, for whom the group average of the detection performance was not different from zero in either synchronous or asynchronous conditions (Christensen et al., 2014, their Fig. 1*B*).

To identify distinct cerebellar areas that are responsible for the deficit in action–perception coupling, a cluster analysis was performed on the APC-index to classify patients as having an affected or unaffected action–perception coupling. Six affected patients were identified with an impaired action–perception coupling (APC-index <0), while the remaining 11 patients were clustered with a positive APC-index (Christensen et al., 2014, their Fig. 3). Lesion symptom mapping was applied, in which the lesions of the 11 unaffected patients were subtracted from the lesions of the affected patients (subtraction analysis). This revealed significant associations of impaired action–perception coupling with the ipsilateral (right) dentate nucleus, lobules V, VI, VIIIa, VIIIb, and IX. Furthermore, lesions of the contralateral (left) Crus II and lobule VIIb were also correlated to impaired action–perception coupling (Christensen et al., 2014, their Fig. 5). This analysis allowed the authors to deduce that an intact ability

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to estimate one's own movements (which requires ipsilateral lobules V and VI) facilitates the detection of synchronous stimuli, that the posterior regions of the cerebellum support sensorimotor integration in the cerebellar-parietal loops, and that both are essential for an intact action-perception coupling.

Christensen et al. (2014) performed a thorough experiment, in which many confounding factors, such as possible oculomotor deficits and movement disorders in the patient group, were taken into account. Furthermore, several permutations of the main behavioral outcome measure (detection performance) were applied to attain a single outcome parameter (APC-index), which is insensitive to any dual task effects. This APC-index was then used to classify patients as affected or unaffected and was used for all secondary analyses. However, the detection performance in the synchronous and asynchronous conditions underlying this outcome measure in the two subgroups (unaffected and affected) was not discussed.

Still, as noted by the authors, action–perception coupling modulation in the patients classified as affected was not just reduced, but actually inversed (as such the terms "(un)affected" and "(un)impaired" are not necessarily accurate). From the data presented, it is not possible to directly compare the behavior in the asynchronous and the synchronous condition for the affected patients, but because their APC-index was negative (Christensen et al., 2014, their Fig. 3), it appears that they performed better in the asynchronous than in the synchronous condition. Notably, some control participants also showed a negative APC-index (the range from zero to the lower 25th percentile; Christensen et al., 2014, their Fig. 3).

The considerations in the preceding paragraph indicate the difficulty of identifying affected patients. For measures with a high interindividual variability in the healthy control group, finding a behavioral cutoff threshold to classify patients as affected or unaffected is not straightforward. For experiments with rare patient populations, however, such a cutoff value is needed, because analyses based on the continuous data lack power for sample sizes smaller than 20 (Timmann et al., 2009). With this cutoff-based approach Christensen et al. (2014) managed to provide a clear link between action–perception coupling and the cerebellum. Furthermore, they should be acknowledged for recruiting a patient sample without any patients who received adjuvant radiotherapy or chemotherapy (since this could have affected extracerebellar brain functions).

Looking beyond the classification of patients as affected or unaffected, the individual patient data suggest that compared with synchronous stimulus presentation, delayed stimulus presentation resulted in worse performance in some patients (APC-index >0), similar performance in others (APC-index $= 0$), and even an improved performance (a facilitatory or less inhibitory effect) in others (APC-index <0; Christensen et al., 2014, their Fig. 3). This raises a question: why does a delayed stimulus presentation result in a facilitatory (or less inhibitory) effect compared with synchronous presentation in these cerebellar patients (and some of the control participants)?

Since the action–perception coupling in these patients is inversely modulated between temporal synchronicity conditions, we suggest that deficits in action–perception coupling in these patients are related to temporal mismatching of processes rather than to a general deficit (which would have resulted in an APC-index of zero). Such temporal mismatching will occur if some processes take more time, for instance if the calculation of the current somatosensory state estimate is delayed. From this perspective, it would be of interest for further research to study the reaction times of the answers in patients with cerebellar lesions compared with controls in a similar paradigm (Jokisch et al., 2005). Results from such an analysis could yield more insight into the possible somatosensory delays in patients. More insight could also be gained from exploring the baseline data, since there is some debate about the involvement of visual perception of (biological) motion in cerebellar patients (Jokisch et al., 2005; Cattaneo et al., 2012). A related issue is whether patients and controls were equally aware that their own arm motion was used in the projection (as in Christensen et al. (2011) in healthy controls).

Christensen et al. (2014) provide valuable insights about the involvement of the cerebellum in the integration of action and perception, applying a lesion symptom mapping approach to an elaborate paradigm to link visual action perception to motor execution. It would be of interest to perform a similar paradigm in control participants in a functional imaging scanner (albeit with wrist rather than arm movements), and compare functional imaging results with these lesion symptom mapping results. Additional information concerning the cerebrocerebellar connections could be gained from non-task-specific imaging analyses as well, for instance using resting-state functional connectivity (Buckner et al., 2011) in a similar patient population.

In conclusion, Christensen et al. (2014) used an effective paradigm to demonstrate the role of distinct areas of the cerebellum in action–perception coupling. They have provided important insights concerning the cerebellum's role, which is a valuable starting point for future studies to investigate the underlying mechanisms of facilitation and inhibition of motor execution on perception in various conditions and patient populations.

References

Buckner RL, Krienen FM, Castellanos A, Diaz JC, Yeo BT (2011) The organization of the human cerebellum estimated by intrinsic functional connectivity. J Neurophysiol 106: 2322–2345. CrossRef Medline

Cattaneo L, Fasanelli M, Andreatta O, Bonifati DM, Barchiesi G, Caruana F (2012) Your actions in my cerebellum: subclinical deficits in action observation in patients with unilateral chronic cerebellar stroke. Cerebellum 11: 264–271. CrossRef Medline

Christensen A, Ilg W, Giese MA (2011) Spatiotemporal tuning of the facilitation of biological motion perception by concurrent motor execution. J Neurosci 31:3493–3499. CrossRef Medline

Christensen A, Giese MA, Sultan F, Mueller OM, Goericke SL, Ilg W, Timmann D (2014) An intact action-perception coupling depends on the integrity of the cerebellum. J Neurosci 34: 6707–6716. CrossRef Medline

Jokisch D, Troje NF, Koch B, Schwarz M, Daum I (2005) Differential involvement of the cerebellum in biological and coherent motion perception. Eur J Neurosci 21:3439–3446. CrossRef Medline

Timmann D, Konczak J, Ilg W, Donchin O, Hermsdörfer J, Gizewski ER, Schoch B (2009) Current advances in lesion-symptom mapping of the human cerebellum. Neuroscience 162:836–851. CrossRef Medline

Wolpert DM, Flanagan JR (2001) Motor prediction. Curr Biol 11:R729–R732. CrossRef Medline