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Does early motor development contribute to speech perception?

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Abstract:	At the end of the target article, Keven and Akins put forward a challenge to the developmental psychology community to consider the development of complex psychological processes, in particular intermodal infant perception, across different levels of analysis. We take up that challenge, and consider the possibility that early emerging stereotypies might help explain the foundations of the link between speech perception and speech production.

At the end of the target article, Keven and Akins (K&A) put forward a challenge to the developmental psychology community to consider the development of complex psychological processes, in particular intermodal infant perception, in light of early appearing motor stereotypies. In this commentary we take up that challenge by considering the role of early motor development in speech perception. Specifically, we address the question of whether the steps in prenatal and early postnatal development in the infant's developing control over tongue movement, could provide information about the size, shape, and movement capabilities of the oral articulatory apparatus, and whether this in turn could provide a mapping onto which both heard and seen speech can be projected. We use as reference previous work from our lab showing that temporarily impeding tongue movement interferes with consonant discrimination in young infants (Bruderer et al. 2015).

K&A provide persuasive argumentation that tongue protrusion and retraction (TP/R), and a host of other behaviours that are categorized as stereotypies, are functionally important for setting the foundation of the aerodigestive system. The stereotypies fall into a class of processes that is spontaneous and activity-dependent. The result of these processes in development, they argue, is an initial organization of the somatosensory and motor cortices relevant for successful coordination and movements of oral-motor articulators involving the mouth and tongue, such as cupping, sucking, breathing and swallowing. We put forward for consideration the hypothesis that these same TP/R and other related stereotypies may simultaneously provide the infant with a mapping of the

shape and configurability of the (upper) vocal tract, and how that changes with movement of the articulators. This in turn, while not necessarily essential for speech perception as it is for aerodigestion, may underlie the infant's integration of heard, seen, and self-produced oral-motor movements even before the onset of babbling.

There is experimental evidence of sensorimotor influences on speech perception in the first six months of life. As highlighted in the target article, infants as young as 4-months (Kuhl & Meltzoff, 1982) and even 2-months (Patterson & Werker, 2003) can match auditory and visual speech, looking longer to the face that matches the sound they are hearing. At 4 to 5-months of age, infants' auditory-visual matching of the vowels "oo" and "ee" is modified if infants purse their lips around a pacifier or their caregiver's finger (into an "oo" configuration) vs. if the infants' lips are stretched by a teething toy or their caregiver's finger (into an "ee" configuration) (Yeung & Werker, 2013).

It has also long been known that from birth infants can discriminate many non-native, and hence unfamiliar speech sounds, and that an important part of speech perception development entails a decline in non-native discrimination by the end of the first year of life (see Werker & Hensch, 2015). Recently we found that at six-months of age, impeding tongue movement can disrupt auditory discrimination of non-native consonants (Bruderer et al., 2015). We tested infants' ability to discriminate the Hindi dental /ɖa/ vs. retroflex /ɖa/ distinction, a non-native, and hence unfamiliar distinction that English learning infants can discriminate at 6-months of age. These consonants are produced by placing the tongue tip either against the back of the front teeth (dental /ɖ/), or against the

roof of the mouth (retroflex /d/). We prevented tongue movements in the experimental condition by having caregivers hold a flat teether over their infants' tongues, and allowed tongue movements in the control condition by having caregivers hold a soft u-shaped teether against their infants' gums. Tongue-impeded infants failed to discriminate the non-native speech sound distinction, while tongue-unimpeded infants successfully discriminated the consonant contrast.

Neuroimaging studies using diffusion track imaging (DTI) in neonates show that the establishment of white matter fiber tract connections that characterize the language pathways in the adult brain has already begun in utero (Perani et al. 2011; Leroy et al., 2011; Dubois et al., 2015). Just 2-days after birth, newborn brains are marked by an established ventral pathway, which will later be responsible for sound-to-meaning mapping; a superior dorsal pathway, extending from the posterior superior temporal sulcus (pSTS) to the premotor areas; and a diminutive inferior dorsal pathway that connects the pSTS to Broca's area (Perani et al., 2011). These dorsal speech pathways underlie speech sound-to-motor processing (e.g. Poeppel, 2012). Within the first few post-natal months, the maturation of the inferior dorsal pathway outpaces that of any other regions within the language network (Leroy et al., 2011). Indeed, motor areas in the inferior frontal cortex – those connected by the inferior dorsal pathway to the auditory cortex – are activated by 7-months of age when infants listen to speech (Kuhl et al., 2014). The presence of these dorsal pathways may be key to our reported behavioural results suggesting motor influences on auditory-visual (Yeung & Werker, 2010) and auditory speech perception (Bruderer et al., 2015).

Prenatal preparation for speech is evident not only in DTI studies of language networks, but also in auditory specialization to both simple sounds and speech sounds by 28-32 weeks gestational age (wGA) as tested in preterm infants with electroencephalography (EEG) (Mahmoudzadeh et al., 2016). Orofacial movements in utero, including TP/R (which is well defined by 28 wGA), could help establish the link between the motor cortex and the auditory cortices. The reported existence of the early appearing dorsal pathway prior to birth (Perani et al., 2011), together with the rapid development of the inferior dorsal pathway in the months following birth (Leroy et al., 2011), provides a plausible means by which sound-to-motor mapping could be established prior to, or immediately upon first experience with, linguistic experiential input.

Stereotypies, including TP/R, may support the functional specialization of the speech pathways specifically dedicated to auditory-motor mapping. A key notion in the target article is that stereotypies, exemplified by TP/R, are activity-dependent processes that contribute to the organization of the somatotopy of the tongue and the lips, as well as the cortico-thalamic (Deck et al., 2013) and the corticobulbar connections (Sarnat, 2015) (pp. 50). The onset of TP/R occurs too late in development to inform neural migration, neurogenesis, or axon pathfinding to S1, but the functional circuitry of S1 is only beginning to be established when these stereotypies first appear (pp. 49). While prenatal structural connections of the linguistic pathways are largely genetically-determined (Kolasinski et al., 2013), spontaneous activity-dependent processes may contribute to their functional

connectivity and integration. Therefore, the dorsal speech pathways that are present at birth may have been organized in part by the stereotypies that first appear in utero.

In summary, as K&A suggest, "*Infants do not 'explore the world by mouth' so much as explore their mouths with the world*" (Keven & Akins, pp. 30). This experience-expectant process (Greenough, 1986) through which self produced stereotypies and externally heard speech interact with emerging anatomical connections, may be the means by which early links between perception and production – even prior to babbling – are established.

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