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COMMENTARY

Considering the updated Input Hypothesis from a neurolinguistic perspective: A response to Lichtman and VanPatten

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The impact of Krashen's Monitor Theory (Krashen, 1982 and elsewhere) on the field of second language (L2) acquisition and on L2 teaching cannot be denied. As described in Lichtman and VanPatten (2021, henceforth "L&VP"), it spurred on theory development in the field, often in reaction to critiques of the Monitor Theory, and it led to the development of particular instructional approaches (e.g., the Natural Approach; Krashen, 1995), even if these were not widely adopted. The essence of Krashen's central ideas certainly remains present in our field, and updated testable hypotheses based on these ideas merit consideration as posited in L&VP. In this response, I primarily focus on L&VP's updated version of the Input Hypothesis from a neurolinguistic perspective. In particular, I consider whether brain-based empirical evidence is consistent with the first statement from L&VP's updated version of the Input Hypothesis: "*The principal data for the acquisition of language is found in the communicatively embedded comprehensible input that learners receive*" (p. xxx). I also touch upon output, explicit information, and the learning/acquisition distinction in the context of the evidence that I discuss before offering conclusions.

What brain-based empirical evidence is most relevant for L&VP's updated Input Hypothesis (2021)? It seems that studies that provide learners with input alone (e.g., without metalinguistic information and without opportunities for production) would be informative to the hypothesis as these studies could reveal whether input is sufficient to lead to learning.[1] Indeed, there are learning paradigms that provide input alone to participants in behavioral and neural experiments. For example, research with statistical learning and implicit learning paradigms, which expose learners to statistically structured input or input derived from an artificial grammar respectively, demonstrate learning after exposure to input alone (Christiansen, 2019; Frost et al.,

[1]I will use the term "learning" throughout this response as a general term to refer to L2 "learning," "acquisition," and/or "development." My use of "learning" should not be interpreted as specific to Krashen's (1982) definition of learning as noted in L&VP (2021).

2019; Perruchet & Pacton, 2006), with potential implications for language learning. However, in the vast majority of these studies, input is devoid of meaning and thus is not directly relevant to the hypothesis about "communicatively embedded" input, which I interpret as entailing meaningful input. Therefore, I do not consider brain-based research on statistical and implicit learning in the current response, although I would like to make one brief point about this literature. Interestingly, if one looks that the neural processes that are elicited by these paradigms, there seems to be some overlap with the neural processes of natural language (Christiansen et al., 2012; Tabullo et al., 2013). In addition, in a meta-analysis of neural substrates associated with grammar, Tagarelli et al. (2019) found significant overlap between the neural activation evidenced in artificial grammar studies (often used in implicit learning paradigms) and that evidenced in natural language studies, with the most common and largest area of activation overlap being Broca's area. In my view, an important, but open, question is the extent of the relevance of the statistical and implicit learning literature for L2 (Morgan-Short, 2020). If these paradigms are valid for understanding aspects of L2 learning, they could be relevant for the updated Input Hypothesis posited by L&VP (2021) given their input-based designs. Importantly though, further empirical work is needed to establish their validity for natural L2s.

Some brain-based studies have provided learners with input alone that is meaningful. As this approach seems to be the most relevant for considering whether communicatively embedded comprehensible input serves as the principal data for the acquisition of language, I consider these studies in more depth. To my knowledge at the time of writing this response, there are four brain-based studies that provide meaningful input alone. These studies either employ event-related potentials (ERPs) to examine neural processes or functional magnetic resonance imaging (fMRI) to examine the neural substrates that are active during language processing. To be able to describe these studies, I first provide a very brief and general overview of ERPs and fMRI.

- ERPs are a scalp-recorded measure of the brain's electrical activity related to a cognitive event (Luck, 2014). Particular ERP waveforms have been associated with first language processing (Swaab et al., 2012), including (a) an N400 effect, which is a negativity commonly associated with lexical–semantic processing that occurs over centro-parietal regions of the scalp around 400 ms after the onset of a target word; (b) a P600 effect, which is a positivity often associated with more controlled grammatical processing that occurs over centro-parietal regions around 600 ms after the onset of a target word; and (c) a (left) anterior negativity (L)AN, which is a (less reliably elicited) early negativity sometimes associated with more automatic grammatical processing that occurs around 300 ms over anterior regions, often over the left hemisphere. These ERP components are also found in L2 processing with a few differences (Morgan-Short, 2014; Morgan-Short et al., 2015; Steinhauer et al., 2009). The N400 can be found for L2 grammatical processing at lower or intermediate levels of L2 proficiency. The P600 is commonly elicited for L2 grammatical processing, but more consistently when proficiency is higher. The (L)AN is less commonly evidenced in L2 but can be found at high proficiency, particularly if learners have had extensive and immersion-based L2 exposure.
- fMRI is a neuroimaging technique that reflects the hemodynamic response evoked by a neural event and thus provides a measure of neural activation (Huettel et al., 2004). fMRI evidence has shown temporal lobe activation (particularly in the left temporal lobe) for first language (L1) lexical knowledge, although others neural areas also support the use of lexical knowledge, such as the supramarginal gyrus and the inferior frontal gyrus (Brodmann's areas 45, 47; Ullman, 2006). For L1 grammar, neural activation is typically found in the inferior frontal gyrus, especially in Broca's area (Brodmann's areas 44, 45), as well as in the

superior temporal gyrus, the basal ganglia, and other cortical areas (Ullman, 2006). The typical neural responses from L1 fMRI research often serve as a basis for comparison for L2 research, and research shows that neural activation for L1 and L2 networks largely overlap (Brice et al., 2021, Sulpizio et al., 2020, Tagarelli et al., 2019), although differences in the amount and spread of activation can depend on L2 age of acquisition and proficiency, among other factors.

For the ERP and fMRI studies that I consider (most) relevant to L&VP's updated Input Hypothesis (Lichtman & VanPatten, 2021), it is important to point out that the studies were not designed a priori to examine this hypothesis. Arguably, however, their results can be interpreted in a post hoc manner as being consistent with the hypothesis or not given that they examined L2 learning and the associated neural signatures when learners were provided with meaningful input alone. First, Christiansen et al. (2012) exposed learners to a meaningful artificial grammar in which different grammatical properties indicated different aspects of a graphic scene. Learners were exposed to 60 sentences while viewing their associated scenes and then were asked to judge the correctness of novel sentences while ERP data were recorded. Participants were quite accurate in their judgment (~94% accurate) and showed a P600 response that was similar to that found for natural language processing collected from the same participants. Thus, one could argue that natural language processes were induced by exposure to meaningful input (from an artificial grammar) alone.

Another relevant study was conducted by Batterink and Neville (2013a). In this study, learners were exposed to a miniature version of French. More specifically, one group of learners was exposed to 367 sentences, which were embedded in short stories and accompanied by pictures, and they were asked to respond to comprehension questions. No grammatical rule explanation was provided to this group of learners. After exposure, the learners completed a grammaticality judgment task while ERP data were recorded. Results on the judgment tasks showed learning (accuracy ≥ 63%), with some learners reaching high levels of accuracy. P600 effects were evidenced in learners who reached high levels of accuracy. Thus, meaningful input seemed to lead to language-related neural processing for learners who learned well. Interestingly, Batterink and Neville (2014) also recorded electrophysiological data during exposure. In an analysis of this data, Batterink and Neville (2014) found that whereas an N400 effect was related to better comprehension, an N100 effect, reflecting selective attention, was associated with better L2 learning.

Using a different paradigm based on Leung and William's (2012) semi-artificial language with articles that were associated with (in)animacy, Batterink et al. (2014) exposed learners to 2112 article–noun pairs and asked them to make animacy decisions about the noun that was presented. Learners were never told about the association between articles and (in)animacy. Rather than administering a posttest of knowledge, Batterink et al. (2014) embedded article violations (i.e., an article normally associated with animacy was presented with an inanimate noun) in the stimuli and assessed whether these violations caused reaction time slowdowns and inaccurate responses, which would indicate that participants were learning the correct association between articles and animacy. Indeed, a behavioral analysis of the data provided evidence of these learning effects. The researchers also collected ERPs during exposure to the input and found that learners who did not become aware of the article-animacy association showed early negative ERP effects and that learners who did become aware of these associations showed P600s. Thus, meaningful input alone led to natural language processing but with differing types of neural processes based on awareness.

Finally, Wong et al. (2013) exposed learners to words that were formed based on a complex, meaningful artificial morphophonological system. After a training phrase in which 432 items were presented along with their associated images, learners completed a forced-choice task selecting the word that matched an image while fMRI data were collected. The behavioral results indicated that learners performed above chance (accuracy > 61%) on the forced-choice task, which provided evidence of learning. The fMRI analyses revealed activation in the striatum, a part of the basal ganglia, which has been associated with natural language grammatical processing and learning (see above). Thus, being exposed to meaningful input alone resulted in neural activity associated with natural language.

In all, the results from these four studies suggest that exposure to meaningful L2 input alone can lead to learning and to the engagement of neural signatures that have independently been associated with language. Moreover, the results may be reasonably interpreted as being consistent with the statement that: *The principal data for the acquisition of language is found in the communicatively embedded comprehensible input that learners receive*. However, there are a few caveats to consider. In each of the studies reviewed above, except for Christiansen et al. (2012), the finding of brain-based evidence for language processing comes with a qualifying factor. For example, in Batterink and Neville's (2013a, 2014) research, the elicitation of the P600 depended on the level of performance, which was shown to be associated with awareness and was predicted by selective attention. In Batterink et al.'s (2014) study, learners with or without awareness evidenced different ERP effects, with unaware learners showing an early negativity and aware learners showing a P600. And in Wong et al.'s (2013) study, the activation in the striatum was found for learners with a specific genetic profile. Thus, the link between input and the engagement of language-related neural processing may be mediated by attention (e.g., with selective attention to a form), awareness (e.g., with explicit knowledge about a form-meaning connection), proficiency (e.g., at higher levels of proficiency), and/or individual difference factors (e.g., with a given genetic profile).

Up to this point, I have only considered brain-based studies that provide meaningful input alone, but we might also consider studies that provided opportunities for output, which can draw learner's attention to gaps in their knowledge and to subsequent input (Gass & Mackey, 2015; Swain, 1993; VanPatten, 2015), and studies that provide explicit information, which would make learners aware of metalinguistic rules. In brain-based L2 training studies that provide groups of learners with input along with opportunities for production, but without metalinguistic information (Friederici et al., 2002; Morgan-Short et al., 2010, 2012; Mueller, 2009; Mueller et al., 2005, 2007), learners appear to (a) reach quite high levels of proficiency (accuracy > 80%), and (b) show fuller language-related neural processing profiles including the P600 as well as the (L)AN effect (e.g., Friederici et al., 2002; Morgan-Short et al., 2012). Thus, opportunities to produce output, in addition to processing input, may be beneficial for L2 learning and for the engagement of language-related neural processing. These studies do not reveal the mechanism through which output contributes to development, but one possibility is that it helps learners direct their attention to subsequent input. Intriguingly, brain-based studies that provide metalinguistic information to L2 learners in addition to meaningful input (and output) have not yet evidenced the development of the (L)AN effect (Batterink & Neville, 2013a; Morgan-Short et al., 2010, 2012), even as learners reach high levels of proficiency and show the P600. Note, however, that one should exercise caution when comparing studies that provide explicit information and/or opportunities for output to studies that provide only input because the amount of exposure to input or overall time on task may differ among studies. If this is the case, then any differences in L2 learning or the engagement of neural processes could be due to increased exposure and/or time on task rather that input/output or explicit/implicit manipulations.

Overall, results from brain-based studies that provide meaningful L2 input alone (Batterink & Neville, 2013a, 2014; Batterink et al., 2014; Christiansen et al., 2012; Wong et al., 2013) suggest that such input can lead to L2 learning and the engagement of language-related neural signatures. However, after considering caveats from these input-based studies along with results from other related brain-based studies, I would like to offer an amendment to the updated Input Hypothesis for consideration: Linguistic or cognitive devices may also be needed to draw attention to L2 forms to interpret their meaning. However, I believe that this "amendment" is not a new idea but rather reflects ideas previously posited by field. For example, VanPatten's Input Processing theory (VanPatten, 2015) states that L2 learners may not naturally focus on form when processing for meaning and that it may be beneficial to structure L2 input so that it draws attention to form when processing for meaning, as in the Processing Instruction approach (see VanPatten, 2005 for information about Processing Instruction). Recall that in Batterink and Neville's (2014) analysis, it was not the ERP component associated with lexical processing—the N400—that predicted increased development but rather the ERP component—the N100—that was associated with selective attention. Thus, learners may benefit from techniques such as Processing Instruction or other types of task-essential practice in which they have to attend to an L2 form for meaning to do something with it. Perhaps the concept of "communicatively embedded input" referred to in the updated Input Hypothesis is expected to have the effect of drawing attention to form when processing L2 input for meaning.

Finally, I would also like to make one point about the acquisition/learning distinction from a neurolinguistic perspective: The point is simply that the ERP effects discussed in this response, unfortunately, do not help us distinguish between "acquisition" and "learning" (Krashen, 1982). Although it has been argued that the (L)AN may reflect implicit processing, and the P600 may reflect explicit processing (Batterink & Neville, 2013b), in L2 research, these effects generally reflect processing at a certain point of time (e.g., on a posttest) and have rarely been examined online while learners are exposed to an L2 and are engaged in the process of learning. So, although neurolinguistic studies can shed some light on many questions about L2 learning, they are not a panacea for our complex questions. However, experimental designs in which ERP measures or other online measures are collected during exposure to L2 input might provide unique sets of data that speak to our questions.

To conclude, results from neurolinguistic studies that provide learners with meaningful L2 input alone indicate that input may be sufficient to bring about some level of learning and language-related neural processing. This is quite remarkable and reveals the plasticity of our brain in regard to language learning even as adults. This finding is also impactful when considering L2 pedagogy. Language instructors and program designers should be cognizant of the fact that textbooks predominantly provide opportunities for L2 output practice. Thus, practitioners should actively work to provide meaningful input opportunities to learners as well. Although this set of results is generally consistent with L&VP's updated Input Hypothesis (Lichtman & VanPatten, 2021) that "*The principal data for the acquisition of language is found in the communicatively embedded comprehensible input that learners receive*" (p. xxx), future behavioral and neural research will be needed to more fully test the hypothesis. In particular, studies that test the effects of "communicatively embedded comprehensible input" and the extent to which such input drives learning with or without other linguistic and/or cognitive devices that direct learner attention to the meaning of L2 forms may be particularly informative to our field.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

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