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AUTHORS' RESPONSE

Toward a model of multiple paths to language learning: Response to commentaries

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Language learning, while seemingly effortless for young learners, is a complex process involving many interacting pieces, both within the child and in their language-learning environments, which can result in unique language learning trajectories and outcomes. How does the brain adjust to or accommodate the myriad variations that occur during this developmental process. How does it adapt and change over time? In our review, we proposed that the timing, quantity, and quality of children's early language experiences, particularly during an early sensitive period for the acquisition of phonology, shape the establishment of neural phonological representations that are used to establish and support phonological working memory (PWM). The efficiency of the PWM system in turn, we argued, influences the acquisition and processing of more complex aspects of language. In brief, we proposed that experience modulates later language outcomes through its early effects on PWM. We supported this claim by reviewing research from several unique groups of language learners who experience delayed exposure to language (children with cochlear implants [CI] or internationally adopted [IA] children, and children with either impoverished [signing deaf children with hearing parents)] or enriched [bilingual] early language experiences). By comparing PWM and language outcomes in these groups, we sought to highlight general patterns in language development that emerge based on variation in early language exposure.

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Moving forward, we also proposed that the language acquisition patterns in these groups, and others, can be used to understand how variability in early language input might affect the neural systems supporting language development and how this might affect language learning itself.

We were motivated to write this review not only to encourage discussion of our specific proposal but also to jump-start broader discussion of variation in language learning in order to better understand the neural mechanisms that support language development in its varied forms. While previous research has delved into nontypical learners to some extent, we feel that greater progress in our understanding of language learning requires that we move beyond the stereotypical monolingual native speaker model that has typified much of the field's efforts to date. Judging by the commentaries written in response to our article, we appear to have succeeded. The commentaries were insightful, spanned a very wide range of topics, and invite deeper and broader discussion of issues raised by our proposals. We thank all the authors for their conscientious consideration of our article and their contribution to what hopefully will be a continued discussion of these issues.

Two general themes emerged from the commentaries we received. First, several commentators identified details that were not explicitly discussed in our article, but which have important implications for a more nuanced understanding of the role of early experience in language learning; all of these suggestions provide interesting and important avenues for further and more refined investigations. For example, Hamann emphasizes the importance of carefully considering the properties of the tasks used to assess PWM (e.g., how similar or different the stimuli are to participants' own language) as well as the characteristics of learners themselves (e.g., prior vocabulary knowledge and socioeconomic status). We completely agree with these concerns, and the available literature we reviewed was quite variable with respect to the methods and tasks used. Archibald highlights the importance of considering task demands and also questions what specific component (or components) of PWM might be affected by variation in early experience, while O'Grady outlines how variation in PWM might play a role specifically in grammatical development. In a related vein, Hunter and Pisoni argue that the terms we used to describe phonological representations, such as "underspecified" and "weak," while providing a useful starting point for considering the effects of early experience, lack necessary precision and clarity to advance our understanding of the specific ways in which the brain is affected by different types of language input. Juffs even questions whether we need the construct of PWM at all, or whether variation in phonological representations alone is enough to explain later differences in language outcomes. Finally, Kroll, Takahesu, Tabori, and Mech call on researchers of bilingual and second language learners to discuss how variation in children and their learning environments might tune neural networks for language regulation and control. They describe how models, such as what we have proposed, can be used to conceptualize and refine further research. It is our hope that what we have proposed can provide a framework to consider and further test a number of issues in an increasingly nuanced way.

The second general issue discussed by several commentators is that while PWM is important, it is undoubtedly not the whole story. Rather, PWM exists within a larger system of interrelated cognitive processes necessary for language learning.

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Although our current focus has been on PWM, which to us is the most salient component when considering early phonological variation, we of course agree with this call for a broader perspective and the commentaries supporting it. In this regard, for example, Archibald argues that other systems in addition to PWM might influence language learning and that the extent to which WM actually constrains language learning might depend on task demands, as noted earlier. Hamann explores how the relationship between phonological and syntactic competence cannot be explained by PWM alone and may reflect other working memory processes. In a related vein, Thiessen argues that, in addition to PWM, domain-general cognitive systems (in particular, long term memory [LTM], attention, and statistical learning) are needed to explain the long-term outcomes of language learning (and variation in those outcomes). Considering bilingual language learners, Hsin suggests that the bilingual advantages we discussed do not necessarily arise solely from WM/executive function (EF) advantages, but may arise from other advantages linked to the nature of bilingual learning environments; Kaushanskaya reminds us that the evidence for a bilingual cognitive advantage is strongly contested in some quarters.

For the remainder of this response, we discuss these two themes in more detail. To begin, we discuss ways in which the framework we have proposed should be modified and how it could be used to generate new predictions following suggestions from the commentaries, to better reflect the nuances and complexities of the phenomena we seek to understand. We then discuss the importance of considering the influence of early experience within a broader context of interconnected language learning and cognitive processes. Finally, we offer an alternative view of what constitutes typical language development (see also Kroll et al., this issue).

GREATER PRECISION OF TASK DEMANDS AND INDIVIDUAL VARIABILITY

In our article, we focused on the role that language experience plays in the development of working memory (WM), in particular PWM. We believe WM to be a distinct system, albeit one that is highly interrelated with other language, attention, and memory processes. We also argue that all children are born with the capacity for memory, but that the substance of memory is instantiated through experience; that is, it becomes memory for "something." At the same time, as many theorists have argued, the nature of memory appears to be modular such that memory for the sounds of language, for example, or visuospatial memory, are processed in distinct ways, though they may be supported by similar underlying mechanisms (e.g., Baddeley, 2012; Eichenbaum & Cohen, 2004). Thus, we argue that PWM, as opposed to other types of WM, is particularly affected by variations in language experience because of the unique status that phonology holds for the development of language. In brief, PWM is developed and made more efficient through experience with the types of stimuli that ultimately support its role in language learning.

In a thought-provoking commentary, Juffs questions the very existence of PWM distinct from phonological representations. He argues that experience-based variation in phonological representations alone might be enough to explain differences between groups of language learners with different early experiences, rendering

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PWM an epiphenomenon. This is an intriguing argument that calls on evidence directly linking exposure to phonology and phonotactics to vocabulary knowledge (French & O'Brien, 2008; MacKenzie, Curtin, & Graham, 2012), and that proposes further how the relationship between phonological knowledge/representations and PWM could be teased apart. Nonetheless, it is difficult to see how representations alone, even those of very high quality that have been firmly established, could be used to build language since, on logical grounds alone, it seems that a mechanism for storing those representations and using them to build words and grammar is required. That being said, the observation that PWM may not be critical at all stages of language development underlines findings that there is a reciprocal relationship between PWM and language learning, as we discussed in our review. Moreover, as Hunter and Pisoni point out, the nature and impact of factors such as signal degradation may differ for different groups of learners, leading to phonological representations that are "underspecified" in different ways. Thus, moving forward, it would be critical to clarify the nature of PWM itself, both the units that are the content of PWM and precisely how the quality of those units might vary and thus influence language learning.

Clarifying the nature of PWM and its role in specific aspects of language learning could be accomplished, in part, by careful consideration of the demands of alternative PWM tasks, as well as the characteristics of the learners themselves, both issues that were raised in the commentaries we received. By considering these factors and making selective comparisons between groups with different early language experiences, we may be able to build a more detailed and comprehensive model of the effects of early variation on language outcomes (e.g., as discussed by Kroll et al.). For example, both children born profoundly deaf who receive CIs and IA children experience delayed exposure to the language they will ultimately go on to learn. However, CI children also often experience degraded input following implantation whereas IA children have full and high-quality input from their new language. Thus, a comparison between these two groups could help to delineate the specific influence of quality and timing of input on PWM. However, as this example illustrates, while useful, such comparisons are complex since multiple differences may be at play; in our example, CI children also lack auditory and linguistic input very early on in development while IA children have some, perhaps limited, input to the birth language within the typical timeframe. Thus, researchers will need to show ingenuity to tease apart the effects of these multiple differences.

At the same time, specific learner characteristics and task demands might also impact what aspect of PWM is assessed, as well as how PWM relates to language outcomes. For example, Archibald points out that WM involves, at minimum, attention, rapid encoding, storage, and rehearsal processes, and that each of these components of WM might draw on stored LTM knowledge to different degrees and in different ways. Critically, different PWM tasks might tap different components of PWM and LTM to varying degrees depending on the nature of the stimuli and specific task demands. It is often found that tasks with high processing and storage demands are more strongly linked to WM in general, so that differences in PWM may be more likely to be observed during linguistically demanding tasks, such as reading. Archibald also argues that we need to carefully evaluate how real-world constraints on language learning or language use are interpreted given

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specific task demands, and how these constraints operate outside experimental testing contexts. Along similar lines, Hamann presents findings that demonstrate how different commonly used PWM tasks (e.g., nonword and sentence repetition) elicit different outcomes depending on how similar stimuli are to a specific language. Hamann argues, and we agree, that variation on these parameters can influence the degree to which a given task reflects WM in general (i.e., if language familiarity is removed or controlled) versus PWM in particular (i.e., if stimuli are highly language specific and stored language knowledge can be used to support performance), and even whether additional abilities, such as syntactic competence, are necessary to perform a task proficiently. Because the degree to which a PWM task relies on linguistic knowledge will impact the performance of different groups, specific task parameters must be considered when interpreting PWM outcomes, particularly when comparing findings across different groups of language learners on different languages.

A major tenet of our review is that PWM outcomes differ depending on prior and concurrent language experience *because* language-specific experiences act as a foundation to support the development and efficient use of PWM processes. In contrast, we have argued that WM in general is not affected by early language experience and, moreover, that language learning following an initial delay might actually be supported by more general memory and EF abilities that might mask underlying PWM differences. This makes the distinction between PWM and WM critically important, and we would argue that the PWM differences across groups based on linguistic knowledge is interesting and relevant, as it highlights the role of experience in shaping PWM. Consideration of specific characteristics of learner groups and tasks thus raises a broader, overarching issue; that is, how is PWM operationally defined?

That the specific parameters of PWM tasks might impact different groups of learners differentially highlights yet another important issue raised by commentators; that is, certain experiences above and beyond the factors we have considered in our review might have generalized effects on the timing, quality, and/or quantity of language input in all groups. For example, socioeconomic status has been found to influence language development, including vocabulary size, in a wide range of language learner groups (e.g., Fernald, Marchman, & Weisleder, 2013; Hart & Risley, 1995; Hoff, 2003). Because of the reciprocal nature between PWM and language ability, socioeconomic status-based differences in vocabulary size might impact PWM outcomes differentially; the same might be true for other factors, such as early parent–child interactions (e.g., Rowe, 2008), genetic/family based predispositions toward language disability or aptitude (e.g., Fisher & DeFries, 2002; MacDermot et al., 2005), or others. Moreover, group characteristics might interact with task demands to lead to unexpected performance differences on PWM tasks. For example, as discussed previously, Hamann presented findings demonstrating that the similarity of stimuli in nonword repetition tasks to specific languages can influence task performance depending on the degree to which individuals were able to draw on LTM (i.e., the size of their acquired vocabulary, or how familiar they were with a given language). Findings such as these have been reported often (e.g., Coady & Aslin, 2004; Keren-Portnoy, Vihman, DePaolis, Whitaker, & Williams, 2010), and we discussed some of them in our review as they relate to

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bilingual language learners (e.g., Messer, Leseman, Boom, & Mayo, 2010; Parra, Hoff, & Core, 2010; Thorn & Gathercole, 1999).

Understanding the unique interactions of task and group factors as they relate to the timing, quality, and quantity of language input, and how they affect language learning in both the short and long term (e.g., see O'Grady, this volume), would move us toward a more precise specification of the nature of the phonological representations established by particular early experiences. However, to achieve this level of precision probably calls for more precise methods of assessing PWM and alternative testing methods.

TAKING A BROADER COGNITIVE PERSPECTIVE

Another theme that emerged in a number of commentaries was that, although PWM arguably plays a critical role in language acquisition, it of course exists within a much larger system of interrelated processes that include general cognitive systems. Specifically, commentaries argued that attention and memory (e.g., Archibald, Hamann, Thiessen), EF, and perhaps even other related abilities, for example, theory of mind (e.g., Hsin), must be considered. Extensive discussion of these systems was and is beyond the scope of our proposal at present; nevertheless, in response to the commentaries, we touch on them briefly here to highlight their importance and to propose how our framework might be broadened to include some of these systems. We think about the roles of domain-general systems here in two ways: first, in terms of their role during "typical" language development, and second, in terms of their possible recruitment as compensatory systems under circumstances of delayed or degraded input. This discussion is necessarily truncated, but serves to provide a very brief overview of the complex interactions between PWM, language acquisition, and domain-general cognitive systems, an area that warrants much further research.

During the earliest stages of language development, infants must learn what elements of the speech stream are important and how those elements fit together to form language. We have argued that it is during this time that phonological representations are acquired and used to create an efficient PWM system. At the same time, Thiessen draws our attention to the critical ways that attention, statistical learning, and LTM may interact to support the acquisition of critical elements of language, such as phoneme categories, lexical stress, and word boundaries. Specifically, Thiessen describes how attentional processes can be used to acquire the statistical regularities in language input and how attention itself can be shaped by input so that learners come to preferentially attend to critical linguistic elements and features. In this view, "learners do not simply reflect the statistical structure of the input. Rather, as their knowledge grows, learners implicitly and explicitly focus on aspects of the input that are likely to be relevant or informative" (Thiessen, this issue). In other words, there is not simply a passive relationship between experience and the establishment of phonological representations, but rather an active interaction between the learner and the environment that changes what is most salient in the input over time. In this way, the use of linguistic cues present in the environment differentially "depends on the interplay among prior experience, working memory, long-term memory, and attention" (Thiessen, this issue).

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We agree with Thiessen's arguments wholeheartedly. There is a rich body of evidence demonstrating that statistical learning mechanisms are used during early stages of phonological acquisition; that the instantiation of phonological distributions depends on native language input; and that knowledge about phonological distributions in the language input changes the saliency of phonological input during the course of development (e.g., Aslin, & Newport, 2012, 2014; Maye, Weiss, & Aslin, 2008; Maye, Werker, & Gerken, 2002; Werker, Yeung, & Yoshida, 2012; Yoshida, Pons, Maye, & Werker, 2010). Viewed in this way, attention might be conceptualized as a conduit by which environmental input becomes directed toward a particular interpretation or a specific stream of processing. For example, if an English-learner who has determined from his or her language environment that the distinction between /ra/ and /la/ is meaningful and thus important, she or he will continue to preferentially attend to that contrast in the input even if she or he is placed in a Japanese-language context in which the distinction no longer carries meaning. In contrast, a Japanese-learner placed in an English language context will likely ignore that difference because they have learned that it is an irrelevant distinction. Critically, the actual acoustic differences between stimuli have not changed, but learners' attention has been shaped to hone in on critical elements of language input while ignoring others. Applying this to our current framework, preferential attention to stimulus features that match learned phonological representations mean that those representations are more likely to be activated and thus strengthened over time. This may be one means by which they come to be more efficiently processed by the PWM system when compared to "irrelevant" acoustic information that may be ignored or processed via complementary or ancillary systems, as we noted in our review. In Thiessen's view, learning phonological categories beyond an early critical period might present a challenge because the learner no longer engages attention automatically to learn critical distinctions (as in the case of children with CIs) or it might result in the creation of new representations within a previously established distribution of language sounds (as in the case of IA children).

Archibald highlights yet another way in which PWM might operate within the context of more general cognitive systems. Specifically, she discusses the changing relationship between PWM and LTM over the course of language development. More specifically, while PWM abilities predict vocabulary outcomes early in development, vocabulary growth later in development becomes lexically supported, such that the relationship between PWM and vocabulary no longer holds. In other words, the neural systems that are recruited for language learning and processing might depend on prior knowledge and the learner's developmental stage. In our review, our focus was on early experiences, particularly those that happen within the first 2 years of life. As such, it may be that early experience influences some aspects of language acquisition through the storage of lexical and grammatical items in LTM. That is, because PWM abilities *are* positively related to vocabulary growth during early stages of language acquisition (i.e., prior to 4 or 5 years of age), early limitations in phonological representations might slow vocabulary growth. Fewer vocabulary items in LTM means less stored information to support PWM processing and further vocabulary acquisition. However, later in development, learners may have acquired sufficient vocabulary to mask initial limitations in PWM due to reduced, delayed, or degraded input early on. Thus, early differences in PWM

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capacity may not necessarily prevent the attainment of high levels of language proficiency. Although our critical focus was on the beginning of the language acquisition process, it may of course be the case that later in development other cognitive systems play an increasingly important role, particularly when changes in the language environment, for example, might elicit additional support from other cognitive systems.

We proposed that domain-general systems can take on a compensatory role in language learning following language delay or reduced or degraded language input. This argument was based on evidence that although PWM is initially open with respect to language development, it becomes fine-tuned as a result of specific language experiences. Therefore, we argued, other cognitive systems may be recruited to support acquisition and processing of a language that is acquired outside of that initial developmental stage. The recruitment of ancillary systems might explain why some learners are able to attain very high levels of language proficiency, despite showing selective difficulties in PWM (see also Kroll et al., this issue; Pierce, Genesee, & Klein, 2016).

One group of language learners for whom the activation of domain-general systems during language processing has frequently been observed and who merit attention here because of the controversy surrounding this evidence are bilinguals (e.g., Abutalebi & Green, 2007). Some research reports that bilinguals are better able than monolinguals to recruit certain domain-general cognitive systems during problem solving (e.g., Bialystok, 2017; Delcenserie & Genesee, 2016); in contrast, these findings and conclusions have been contested by others (e.g., Hsin, this issue; Kaushanskaya, this issue; Morton & Harper, 2007). As noted in the case of the other learner groups under consideration in our review, it seems likely that evidence for or against a bilingual advantage may reflect specific characteristics of both the participants and the tasks used to test this hypothesis, and this may account in part for the lack of consensus in the literature. Moreover, it seems likely that the bilingual advantage reported in tightly controlled experiments is very labile and often overridden by other factors when bilinguals are observed in real-world contexts where multiple factors can influence behavior. Space limitations do not allow us to get into this issue in depth, but suffice to say here that the case of bilinguals is complex and remains unresolved. Bilinguals were included in our review as a potentially useful counterpoint to the other cases we discuss, all of whom experience what might be considered disadvantaged early experiences (e.g., delayed exposure to language or degraded language input), a point we return to at the end.

Before leaving this section, we suggest that evidence for the adaptive or compensatory role of additional domain-general cognitive systems in language acquisition might also come from investigating other groups of extraordinary language learners. For example, children with specific language impairment receive early language input that should be sufficient to establish phonological representations and the PWM system that we argue underpins typical language development. However, they often have a selective difficulty in this domain and, of course, in their general language learning outcomes (e.g., Gathercole, 2006). What accounts for their poor performance with this aspect of language? Is their deficit specific to PWM or are other domain-general systems involved? In contrast, *language savants* appear to

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be exceptionally good language learners who become highly proficient at new languages even when they are acquired in adulthood (Smith & Tsimpli, 1995; Smith, Tsimpli, Morgan, & Woll, 2010). What accounts for their performance? Is it that they are not subject to the same critical period constraints as other learners? Do they have the ability to reopen critical periods, or are they able to draw on ancillary cognitive systems in order to acquire and use additional languages?

CONCLUSION

In their commentary, Kroll et al. discuss how variation in language exposure could interact with characteristics of individuals or groups of learners to tune neural networks in specific ways that could provide both costs and benefits for language learning. That is, an initial cost might prove to be a benefit at a later point in time, or vice versa, depending on specific task requirements and the neural systems available to support learners' performance. Kroll's comments on the changing nature of costs and benefits at different stages of development highlight the utility of tackling the interaction between early experience and subsequent language development through a lens of neural adaptation. Applying this view to our review, we assume that there is a sensitive period of neural plasticity early in development during which the brain sets up a foundation for the language it will ultimately acquire. In the case of children growing up in a monolingual language environment, the phonological representations and the resulting PWM system that develops in that context can directly support the acquisition and use of more complex abilities in that language. However, other language learning groups, such as those we have discussed, often experience a mismatch between, or change in, their early and later language environments. More specifically, the language environment, including the specific language (e.g., in the case of IA children), the language modality (e.g., for children who become deaf at different stages of development and switch between signing and spoken languages), the amount of language input (e.g., children with otitis media), or the complexity of the language environment (e.g., children who experience otitis media, or successive bilinguals who are exposed to their second language following a delay), could all change at different points in development. From a neural adaptation perspective then, investigating how well an early language context matches a context experienced later in development could reveal (a) whether and how an early established foundation for language learning is able to support learning in the new context, and (b) whether additional mechanisms can be deployed to support acquisition of a new language.

Addressing these issues is particularly apt insofar as evidence indicates that lags in PWM do not appear to preclude the achievement of high levels of proficiency in either a first or second language. As we have suggested, it may be the case that adaptive or compensatory mechanisms are developed and applied when the language learning environment changes; that sensitive periods for phonological acquisition can be extended or reopened following a change in context later in development; or that some other mechanism is available to support language acquisition when variation or delay in language input occurs. In these cases, and as discussed by Kroll et al., an initial cost could prove to be a benefit as more adaptive or flexible mechanisms might be deployed than would otherwise be available, for example, as

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might occur for bilingual language learners who ultimately experience a cognitive advantage. In contrast, it may be that there is a limit to the amount of variability or delay that neural systems can handle. Investigating the influence of changes in language context could provide insights into how the brain adapts and how this might impact the language acquisition system as it responds to a language learning environment that differs from the initial learning context in specified ways. Comparing PWM and language outcomes between groups with different early language experiences, as we have done in our review, is one way in which we can begin to identify how the PWM system is initially set up for and subsequently processes language and how adaptive it is to changes in the language learning environment. Moving forward, we hope that our review invites more research regarding the role of PWM in language in these groups of language learners and possibly others not considered here. Of course, research on early language learning will necessarily converge with basic research on domain-general processes such as learning, memory, attention, and critical periods. This in turn may lead to new theories and predictions about neural plasticity in response to changes in language learning environments. For example, investigations of critical periods have revealed some of the processes that occur when neural circuits become stabilized over time (e.g., for a review, see Werker & Hensch, 2015), and studies of experience-dependent plasticity demonstrate under what conditions neural circuits are likely to be modified and refined (e.g., Fox & Wong, 2005; Shibata et al., 2017). These lines of basic brain research open new possibilities for language researchers to explore.

From a practical point of view, understanding how the brain responds to changes in the language environment at different points in development could ultimately reveal when and how to support individuals when language difficulty arises, and could even lead to the development of interventions targeted to specific language-learning groups. Finally, and in conclusion, understanding variation in language development in this way might ultimately reveal that there is not only one but multiple ways to become proficient in language. Thus, our notion of "typical" development may need to be reconceptualized to extend beyond the monolingual case. We concur wholeheartedly with Kroll et al. that "acknowledging the possibilities for new learning afforded by differences among individuals and across contexts of learning provides a much richer framework for understanding language development and its consequences than the dichotomous categories of typical versus atypical" (Kroll et al., this issue).

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