ABSTRACT: Research is reviewed demonstrating perceptual narrowing across a variety of domains. Research is also reviewed showing that the temporal window of perceptual narrowing can be extended and, in some cases, perceptual narrowing can be reversed. Research is also reviewed highlighting the neurophysiological correlates of perceptual narrowing as well as some of the individual neurophysiological differences associated with perceptual narrowing. Various methodological issues associated with perceptual narrowing are also discussed. The broader purpose of this paper, however, is to argue that the term perceptual narrowing fails to capture the dynamic nature of this perceptual process. Finally, it is argued that just as other concepts associated with experience and development are refined and modified as new evidence emerges, likewise we need to evaluate and refine how we conceptualize perceptual narrowing.

INTRODUCTION

As a recent special issue of Developmental Psychobiology attests there is a growing interest in perceptual narrowing. Perceptual narrowing is often described as an experience-dependent perceptual process in which stimuli that were readily discriminated early in development are not readily discriminated later in development. A cursory review of the literature using the term perceptual narrowing within the title, abstract, or keywords reveals that approximately 20 articles were published between 1966 and 2000 and at least 200 articles were published between 2001 and 2014. While this does not represent a full-scale literature search as certainly more than 20 papers were published prior to 2000 that are relevant to the topic of perceptual narrowing it does, however, illustrate the growing interest in the topic of perceptual narrowing.

OVERVIEW

The goal of this paper is to highlight the need for sharpening our current thinking about the developmental process of perceptual narrowing and examine whether the term perceptual narrowing best captures this developmental process. Before doing so however I will provide a brief review examining how prior conceptualizations of experience have changed over time and have influenced our thinking about perceptual narrowing. I will also review recent work examining how experience affects the timing and flexibility of perceptual narrowing. Finally, and given the recent growth of research relevant to perceptual narrowing, I will review some of the neurophysiological correlates of this perceptual process as well as some of the methodological challenges facing investigations of perceptual narrowing. Finally, I will propose an alternate taxonomic scheme for the phenomenon of perceptual narrowing.

NATURE OF EXPERIENCE

The question of how different types of experience, and of course the timing of experience, shape development is of long standing interest within the fields of...
developmental biology, developmental psychology, and more recently developmental neuroscience. Some of the earliest and most well known conceptualizations of the effects of experience on early development come from ethology and developmental psychobiology (see Gottlieb & Kuo, 1976 for a historical review). Gottlieb (1976, 1992), for example, described three distinct categories of experience. The first of these he termed an inductive experience meaning a specific type of experience is necessary to bring forth the development of a specific attribute. The second category of experience he termed a facilitative experience which refers to a type of experience that modulates when an attribute will develop by promoting or inhibiting its development—keeping in mind that the attribute will develop at some point during development irrespective of the occurrence of the facilitative experience. Finally Gottlieb (1976, 1992) described a maintaining or a maintenance type of experience. According to Gottlieb this third type of experience was not necessary for the development of an attribute but is necessary for it to remain developed or present within the organism. As readers of this journal are well aware Gottlieb’s (1976; 1992) conceptualizations of experience have done much to affect our thinking about development and are also relevant to our understanding of perceptual narrowing. Finally, and as noted by others (i.e., Michel & Moore, 1995, p. 118), “experience has always been a challenging concept to define and categorize where Gottlieb’s (1976; 1992) distinctions provide a theoretically rich and empirically based explanation of experience.”

A challenge, however, with any discussion about the effects of experience on early development is to move beyond the level of describing the types and timing of experience to a level of mechanism that we can use to understand and make predictions about how experience affects development (Greenough, Black, and Wallace, 1987, p. 539), for example, proposed an account of experience that they argued addresses the mechanisms by which experience shapes development within different forms of neural plasticity. The first of their proposed mechanisms is what they describe as an experience-expectant process. Experience-expectant processes are defined as information and experiences that are “ubiquitous throughout the evolutionary history of the organism and underlie many of the sensitive and critical period phenomena.” They further explain that such information and experiences are reliably found in the everyday environment of the organism and are necessary for their normative development. The second mechanism proposed by Greenough et al. (1987), also relevant for our understanding of perceptual narrowing, is what they term an experience-dependent process. Experience-dependent processes are defined as “the storage of information and experience that is unique to the individual. In other words because experience differs in its timing and character, the nervous system must be ready to incorporate the information when available” (Greenough et al., 1987, p. 540). Finally, they propose that experience-expectant and experience-dependent processes represent more than descriptions of information and actually represent the neural mechanisms responsible for the generation and maintenance of new synaptic connections in response to idiosyncratic experiences and individual ontogeny.

This cursory overview of experience is important within the context of perceptual narrowing for at least two reasons. First, and as noted by Maurer and Werker (2014), at its core perceptual narrowing exemplifies both experience-expectant and experience-dependent processes. That is, early in development early stimulation or experience promotes infants’ initial perceptual sensitivities (i.e., experience-expectant) and these perceptual sensitivities are refined through individualized experiences during development (i.e., experience-dependent). Second, just as our conceptualizations of experience, as well as our predictions about how experience shapes development have been, and continue to be distilled over time, we must think carefully about how we conceptualize perceptual narrowing. In the sections that follow I will briefly review some of the evidence documenting perceptual narrowing, as well as recent evidence showing behavioral and neurophysiological flexibility within perceptual narrowing. Finally, and in light of recent evidence, I will examine whether the term perceptual narrowing adequately captures the dynamic nature of perceptual development and conclude with some recommendations to guide our thinking and research related to perceptual narrowing.

PERCEPTUAL NARROWING

Some of the most well known, and consequently most frequently cited, examples of perceptual narrowing come from Werker and coworkers (Werker, Gilbert, Humphrey, & Tees, 1981; Werker and Tees, 1984a, 1984b see also Maurer & Werker, 2014 for a review). In these experiments, Werker and coworkers examined whether Hindi-speaking adults, English-speaking adults, and 7- and 12-month-old infants, born to English-speaking adults, discriminate the Hindi retroflex and dental stops (/θ/ & /ð/) as well as the Hindi voiced and voiceless dental stops (/θ/ & /ð/). Their results revealed that English reared 7-month-olds and Hindi-speaking adults were able to discriminate the Hindi retroflex and dental stops as well as voiced and
voiceless stops. In contrast, 12-month-olds and English-speaking adults only discriminated their native English phonemes. In general, infants’ perceptual discrimination of speech phonemes across different languages was shown to be quite broad early in development and over time became attuned to their language-specific experiences (see Werker & Tees, 2005 for a review).

Other evidence of perceptual narrowing comes from infants’ discrimination of faces of other races and evidence shows this “other race effect” (ORE) emerges between 3 and 6 months of age (Hayden, Bhatt, Joseph, & Tanaka, 2007; Kelly et al., 2007, 2009). The ORE is characterized by the fact that up to 6–9 months of age infants show discrimination of faces of their own race as well as faces of other races whereas after 9 months of age infants typically only show discrimination of faces within their own race. Similarly, infants’ discrimination of faces of other species also provides evidence of perceptual narrowing. Pascalis, de Haan, & Nelson (2002) familiarized 6- and 9-month-olds and adults to an unfamiliar human or unfamiliar monkey face and following familiarization participants received two visual paired comparison test trials. Results revealed that 6- and 9-month-olds, as well as adults, showed reliable discrimination of the human faces but only the 6-month-olds showed reliable discrimination of the monkey faces. The results of Pascalis et al. (2002) demonstrate that infants’ discrimination of faces, like speech perception and the ORE, is initially fairly broad and over time becomes attuned to those faces frequently encountered (see Pascalis & Kelly, 2009; Scott, Pascalis, & Nelson, 2007 for reviews).

In addition to face and speech perception, perceptual narrowing has also been shown to occur within infants’ perception of music as well as their multisensory perception of human and non-human auditory-visual communication. Hannon and Trehub (2005a) examined whether adults from Bulgaria or North America, as well as 6- to 7-month-old North American infants, discriminate Bulgarian folk dances that violate both simple and complex rhythmic structure. Importantly, these Bulgarian folk dances include a complex rhythmic or metrical structure that is not found in traditional North American music. The results of Hannon and Trehub (2005a) show that Bulgarian adults, as well as 6- to 7-month-old North American infants, reliably discriminate changes in Bulgarian folk dances that violate both simple and complex rhythmic or metrical structure. In contrast, North American adults discriminate simple but not complex rhythmic changes. Hannon and Trehub (2005b) have also shown that when North American 12-month-olds are provided with 2 weeks of at home exposure to unfamiliar Bulgarian folk dances they, but not North American adults, or North American 12-month-olds without exposure to the Bulgarian folk dances, discriminate changes in both the complex and simple rhythmic structure of the previously unfamiliar music. Thus infants’ discrimination of musical structure or rhythm, like their discrimination of speech, faces of other races and faces other species, is dependent upon their individual exposure to a particular musical structure.

Perceptual narrowing has also been shown within the context of multisensory auditory-visual perception. For example, Lewkowicz and Ghazanfar (2006) demonstrate that 4- and 6-month-olds, but not 8- and 10-month-olds, reliably match monkey coo and grunt calls with the appropriate dynamic monkey facial expression. These results provide the first evidence of perceptual narrowing within the context multisensory auditory-visual events as younger but not older infants show intermodal matching of the monkey faces and vocalizations. Subsequent research by Lewkowicz, Sowinski, and Place (2008) demonstrated that the matching of the 4- and 6-month-olds in Lewkowicz and Ghazanfar (2006) was dependent upon their detection of the audio-visual synchrony between the face and vocalization rather than temporal duration or sensitivity to a higher-order property like affect or valence. Thus what narrowed in Lewkowicz and Ghazanfar (2006) was infants’ detection of the audio-visual synchrony of the monkey faces and vocalizations. Evidence also exists for perceptual narrowing within non-native multisensory audio-visual human speech (e.g., Pons, Lewkowicz, Soto-Faraco, & Sebastián-Gallés, 2009). In this experiment, 6-month-old native English infants and 6-month-old native Spanish infants showed reliable matching of audio-visual speech of English speech sounds, however, by 11 months of age Spanish infants—as well as a sample of Spanish speaking adults—failed to show reliable matching of audio-visual English speech. Not surprisingly, however, English speaking 11-month-olds and adults continued to show reliable intersensory matching of the auditory-visual English speech (Pons et al., 2009).

The experiments described above are important as they represent some of the first investigations of perceptual narrowing across a variety of domains and sensory systems. In general, these studies were met with much excitement and enthusiasm as they capture what Lewkowicz and Ghazanfar (2009) describe as “regressive” perceptual development. That is traditionally research in the area of perceptual development has been what Lewkowicz and Ghazanfar (2009) label as “progressive” because investigators examine when infants develop the capacity for some perceptual skill or ability. In contrast, studies of perceptual narrowing reveal how experience modifies, or fine-tunes, infants’
perceptual development. Important as these early demonstrations of perceptual narrowing are, equally important however, are the questions raised by these experiments—especially as these questions help to shape our understanding of perceptual development. For instance, once perceptual narrowing has occurred can perceptual discrimination of that same attribute or property return—and to what degree? Can the window of perceptual narrowing be extended through continued experience—and for how long? Are some properties or domains more “open” or “closed” than others in terms of their flexibility within the context of perceptual narrowing? What role does the development of attention play within perceptual narrowing? Does perceptual expertise for one category or type of property promote narrowing of a similar but different category or property within the same general domain? Fortunately, recent work has begun to address these issues.

FLEXIBILITY OF PERCEPTUAL NARROWING

While it is unlikely that perceptual narrowing refers to a permanent loss or reduced perceptual sensitivity for all sensory domains, it is possible there are some domains for which perceptual narrowing does in fact result in a permanent loss of perceptual sensitivity. Still, there is growing evidence demonstrating a greater flexibility than perhaps previously assumed within early characterizations of perceptual narrowing. For instance, Werker and Tees (2005, p. 239) state,

“even in our original work, we had found that the declines in performance on nonnative contrasts were not absolute. Subsequent studies using more sensitive behavioral testing procedures (e.g., Tees & Werker, 1984; Werker & Logan, 1985; Werker & Tees, 1984b) showed latent sensitivity to nonnative distinctions, although not at the level of that shown by native speakers (see Polka, 1992) continues to exist.”

For instance, neurophysiological evidence demonstrates that psychoacoustic auditory discrimination of speech phonemes persists even though perceptual discrimination of nonnative speech phonemes is not evident (Aaltonen, Niemi, Nyrke, & Tuukanen, 1987). Moreover, while neurophysiological discrimination of nonnative speech contrasts continues, it tends to occur at different neurophysiological locations compared to discrimination for native speech contrasts (Dehaene-Lambertz, 1997; Rivera-Gaxiola, Csibra, Johnson, & Karmiloff-Smith, 2000). Findings such as these have led Werker and Tees (2005) to argue that continued discrimination of native and nonnative speech contrasts is certainly possible, but likely arises from different neurological generators and characterizes a form of perceptual reorganization rather than a perceptual narrowing. Moreover, Werker and Tees (2005) also point out “there is virtually no system for which some mechanism, at some level, cannot be found to allow further change beyond the point in time at which input would typically have the greatest influence” and they provide evidence of this flexibility within behavioral, molecular, and genetic changes (see Werker & Tees, 2005, pp. 242–243 for examples).

As noted by Werker and Tees (2005) there is greater plasticity and flexibility than previously assumed within the domain of speech perception. In addition, more recent research has examined the plasticity and flexibility of infants’ cross-species face perception. For example, Pascalis et al. (2005) demonstrate that providing 6-month-olds with 3 months of 1–2 min of daily exposure to pictures faces of monkeys the now 9-month-olds continue to show discrimination of monkey faces. A second group of 9-month-olds who did not receive the three months of training, however, failed to show reliable discrimination. Like Pascalis et al. (2005), Scott and Monesson (2009) also demonstrate that 6-month-olds who were trained for 3 months with individually named (i.e., Boris, Dario, etc.) monkey faces, but not categorical labels (i.e., monkey), continued to show discrimination at 9 months of age. They concluded that the individualization of faces might facilitate infants’ attention toward “the unique features of… monkey faces” (p. 678). Together the results of Pascalis et al. (2005) and Scott and Monesson (2009) are important as they demonstrate that cross-species face perception is more flexible, and that the temporal window of perceptual narrowing, is broader than perhaps previously articulated (Pascalis & Kelly, 2009). Finally, and as described by Werker and Tees (2005), these results suggest that changes in infants’ selective attention may lead to a type of perceptual reorganization rather than a permanent decline or perceptual loss.

The studies described above show that infants’ perceptual discrimination of faces, speech, and other properties are subject to perceptual narrowing. Moreover, these studies also demonstrate that neurological and attentional factors likely affect the process of perceptual narrowing. For example, the results of Aaltonen et al. (1987) showed auditory or acoustic discrimination of native and non-native speech contrasts but not perceptual or categorical discrimination of non-native speech contrasts. In other words, discrimination remains possible, yet occurs in different neurological regions, and is likely a result of a type of neurological reorganization (Rivera-Gaxiola et al.,
In addition, the results of Scott and Monesson (2009) show that 9-month-olds reliably discriminate previously unfamiliar monkey faces when they individuate the faces by attending to and learning individual names for each monkey face. Thus when infants’ attention guides them to individuate exemplars of a category, that is, monkey faces, they discriminate within-category members. Together these results demonstrate that perceptual discrimination of some properties remains possible, is affected by infants’ attention, and may also include some level of neurophysiological reorganization. Additional research is needed that continues to examines how the development of attention, as well as various neurophysiological factors, including the development of these neurological factors, affects perceptual narrowing and perceptual development.

REVERSIBILITY OF PERCEPTUAL NARROWING

While experience has been shown to influence or maintain the temporal window of perceptual development (e.g., Pascalis et al., 2005; Scott & Monesson, 2009), until somewhat recently it was not known whether infants could show discrimination of a property after perceptual narrowing of that property occurred. The first evidence for a “reversal” of perceptual narrowing comes from the “other-race-effect” (Sangrigoli et al., 2000). In this experiment, Korean adults who were adopted between 3 and 9 years of age into Caucasian homes, at an age after perceptual narrowing of Caucasian faces had presumably occurred, showed discrimination of Caucasian faces yet failed to show discrimination of Korean faces (Sangrigoli et al., 2005). Moreover, the performance of the Korean adoptees did not differ from native European Caucasians in their discrimination of Caucasian faces but did differ from Korean control subjects thus providing some of the first evidence that the ORE can be reversed (Sangrigoli et al., 2005).

Similar research by de Heering, de Liedekerke, Deboni, & Rossion (2010) revealed that children of Asian origin (Chinese or Vietnamese) who were adopted between 2 and 26 months of age, also into European Caucasian families, performed equally well at discriminating Caucasian faces and Asian faces when tested 6–14 years after adoption. While de Heering et al. (2010) demonstrated that substantial experience could improve children’s discrimination of Caucasian faces, the participants in de Heering et al. (2010), did not show a reversal of the ORE as evidenced by Sangrigoli et al. (2005). Importantly, and as discussed by de Heering et al. (2010), the differences in the results are likely methodological. Specifically, de Heering et al. (2010) used a traditional familiar/novel preference looking procedure whereas Sangrigoli et al. (2005) used a two-alternative forced choice procedure. In addition, de Heering et al. (2010) used a larger sample of participants, a larger set of faces, and masked the external features of the faces (i.e., hairlines).

The methodological differences of de Heering et al. (2010) and Sangrigoli et al. (2005) while relevant to our understanding of the ORE and perceptual narrowing, also underscore the need for caution when interpreting results related to perceptual narrowing. That is, experiments examining the ORE, as well as experiments examining infants’ discrimination of monkey faces (i.e., Fair, Flom, Jones, & Martin, 2012; Pascalis et al., 2002, 2005), typically use static two-dimensional faces and it is often assumed one is describing real dynamic and three-dimensional faces. Thus, and as noted by de Heering et al. (2010) we must be cautious in our discussion of infants’ perception of faces of other races and other species. Still, the results of de Heering et al. (2010) and Sangrigoli et al. (2005) show that substantial experience (i.e., 10+ years) improves, and in some contexts, may reverse the other race effect.

While 10+ years of experience with faces of another race led to an improvement (de Heering et al., 2010) or a reversal (Sangrigoli et al., 2005) of the other race effect, related evidence has shown that 12-month-olds, who typically fail to discriminate unfamiliar monkey faces, will show discrimination of unfamiliar monkey faces when provided an additional 20s of familiarization (Fair et al., 2012). In this experiment, Fair et al. (2012) showed, using the same faces, as well as the same duration of familiarization and test trials used in Pascalis et al. (2005) that 12-month-olds fail to discriminate unfamiliar monkey faces thus replicating Pascalis et al. (2005). In a follow-up experiment, however, Fair et al. (2012) showed when the amount of familiarization to the previously novel monkey face was doubled from 20 to 40s 12-month-olds reliably discriminated the unfamiliar monkey faces. Thus by doubling the time of familiarization from 20 to 40s 12-month-olds showed reliable discrimination of unfamiliar monkey faces and provides additional evidence of a reversal of perceptual narrowing.

1 External features, such as hairline, may provide a reliable clue/cue to discriminating Caucasian faces more than Asian faces because hair texture varies more in Caucasian than in Asian faces.
Within the context of language, research demonstrates that more recent experience with a second language may in some cases override previous experience with one’s native language. For instance, Pallier et al. (2003) examined whether Korean adults who were adopted into French homes between 3 and 8 years of age, and were tested when they were between 20 and 30 years of age, could discriminate words and sentences of their native language, other unfamiliar languages (i.e., Japanese, Polish, Swedish), or their second language (i.e., French). Their results revealed that the Korean adoptees could not behaviorally discriminate sentences or words from their native Korean language, or from other unfamiliar languages, but they did show reliable discrimination of French (i.e., their second language). In addition, fMRI results failed to show any differences in brain activation when the Korean adoptees listened to their native Korean compared with an unfamiliar language. These Korean adoptees pattern of neurological activation to their second language (i.e., French) was similar to native speakers of French (Pallier et al., 2003). In other words these Korean adoptees failed to show any effects or evidence of their prior exposure to or learning of Korean and their behavioral and neurological pattern of responses were similar to native speakers of French (Pallier et al., 2003; see also Ventureyra, Pallier, & Hi-Yon, 2004 for similar results).

The results of Pallier et al. (2003) and those of Ventureyra et al. (2004) described above demonstrate that following adoption, and of course exposure to a second language, children lose the ability to discriminate native speech sounds, as well as other elements of their native language. However, other examinations of speech and language perception with international adoptees and immigrants to the United States has shown that as adults they may reestablish some of their sensitivity to speech contrasts within their first or native language when provided minimal exposure to their native language. For example, children who had spoken Korean exclusively until the age of about 3 years, and then experienced a sharp drop in speaking Korean following immigration, were compared with native speakers of Korean in terms of their production and perception of Korean phonemes (Oh, Jun, Knightly, & Au, 2003). The results of Oh et al. (2003) revealed that after starting a first-year university level Korean class that those children who spoke Korean as young children, were as good as native Korean speakers in terms of discriminating native phonemic contrasts and their speech production. Similarly, native Koreans who were adopted into English speaking homes at a slightly younger age (i.e., 1 year of age), and had less well developed language skills in their native language, also showed discrimination of Korean consonants now as adults following 2 weeks of intensive exposure (50 min a day) to their native Korean language (Oh, Au, & Jun, 2010). Thus evidence demonstrates that following early adoption/immigration and long-term exposure to a second language that re-exposure to one’s native language is often sufficient to “reactivate” discrimination of speech contrasts in one’s native language.

Broadly considered, these results highlight the fact that a “reversal” of perceptual narrowing can occur within different domains. Specifically, prolonged or long-term exposure, may lead to a reversal of perceptual narrowing within the context of speech perception and the other race effect (de Heering et al., 2010; Pallier et al., 2003; Sangrigoli et al., 2005; Ventureyra et al., 2004). In the case of Fair et al. (2012), a reversal of perceptual narrowing occurred when infants were provided a brief one-time exposure to the novel faces of an unfamiliar species. Moreover, these results further highlight the flexibility of the perceptual systems (at least speech perception and production) well into adulthood (Oh et al., 2003, 2010). Future research is needed that examines how the amount, as well as the timing, of additional exposure affects perceptual narrowing. Research is also needed that examines the possibility of reversing perceptual narrowing as well as the stability of such a reversal. Finally, just as the term perceptual narrowing is problematic as it may imply a permanent perceptual decline or loss, claims of a reversal of perceptual narrowing are likely equally problematic. In other words, given that perceptual discrimination, or a lack of perceptual discrimination, is affected by experience and remains flexible during much of development, including adulthood, it seems a more accurate characterization of this perceptual process may be one of perceptual attenuation and attenuation rather than perceptual narrowing or a reversal of narrowing (see Aslin & Pisoni, 1980; Maurer & Werker, 2014).

As previously noted the volume of empirical and theoretical research examining perceptual narrowing has grown much over the past several years (see Lewkowicz & Ghazanfar, 2006; Pascalis & Kelly, 2009; Scott et al., 2007; Slater et al., 2010; Werker & Tews, 2005 for reviews). Despite this growing body of work there are many unanswered empirical questions and theoretical issues that need to be addressed. For instance, and perhaps most critically, what does perceptual narrowing mean? Does, or should, perceptual narrowing describe only those properties that are permanently lost and if so what properties, if any, are permanently lost? Does perceptual narrowing refer to an attenuation or decreased sensitivity to a perceptual property or, as suggested by Werker and Tews (2005), a
perceptual and or neurological reorganization? Is perceptual narrowing best characterized as regressive perceptual development (Lewkowicz & Ghazanfar, 2009)? Moreover, in the words of Scott et al. (2007, p. 201) “what is it that is narrowing” during perceptual development?

**METHODOLOGICAL ISSUES**

Numerous studies of perceptual development, including many examining perceptual narrowing, use a preferential looking procedure (i.e., novelty/familiarity visual preference procedure) to assess infants’ discrimination (e.g., Fair et al., 2012; Kelly et al., 2005; Pascalis et al., 2002, 2005; Simpson, Varga, Frick, & Fragaszy, 2011). Typically experiments using this procedure calculate infants’ proportion of looking to the novel stimuli as an index of perceptual discrimination by dividing the amount of time participants look to the novel stimuli by the amount of time spent looking toward the sum of the novel and the familiar stimuli and this proportion is then compared to a chance value of 50% or equivalent looking to both displays. A variation of the preferential looking procedure, that is, the intermodal matching procedure, has also been successfully used in studies of perceptual narrowing. In this procedure, the participant is typically presented with two side-by-side visual displays and simultaneously hears an auditory event that matches one of the two displays and the dependent variable is the proportion of time the infant looks toward the sound-matching or sound-specified event (Spelke, 1979). The intermodal matching procedure has been successfully used in a variety of contexts, including experiments examining perceptual narrowing, specifically infants’ matching of non-human faces and vocalizations (Flom, Whipple, & Hyde, 2009; Lewkowicz & Ghazanfar, 2006; Lewkowicz, Sowinski, & Place, 2008).

Using a slight variation of the intermodal matching procedure, Pons et al. (2009) examined infants’ perception of audio-visual speech. In this experiment, English and Spanish learning infants were presented with the English /ba/ or /va/ speech sound for 45 s in isolation and were then presented with silent but visible facial speech displays of /ba/ and /va/. The results of Pons et al. (2009) revealed that 6-month-old Spanish and English learning infants showed a reliable preference for the matching face whereas only the 11-month-old English learning infants continued to show a reliable preference toward the matching face. Unlike traditional intermodal matching studies Pons et al. (2009) chose to present the auditory and visual events on sequential trials in order to reduce the possibility of a McGurk type effect and consequently they also introduced a memory component to their procedure.

As described above, the preferential or novelty/familiarity looking procedure, as well as the intermodal matching procedure and its variations, have been successfully used within experiments examining perceptual narrowing that use the infants’ duration or proportion of looking to the novel or matching event as their dependent variable. One study, however, raises a methodological issue regarding the use of the proportion of total looking time.

In an examination of infants cross-species intersensory perception, Flom et al. (2009) presented infants between 6 and 24 months of age with two static images of an unfamiliar dog while hearing one of two different dog barks. One image showed the dog in a play posture and the other image showed the dog in an aggressive posture and they assessed infants’ preferential looking to the sound-matching image after hearing an aggressive or non-aggressive bark. In addition, because infants heard the bark for 1–2 s prior to seeing the images, and the lateral position of the aggressive non-aggressive postures did not change across the trials, they also examined whether infants’ first looks were directed toward the correct posture. Results revealed that the 6-month-olds’ proportion of looking to the sound matched image exceeded chance and the looking behavior of the 12-, 18-, and 24-month-olds failed to exceed chance. Traditionally such a pattern of results would be viewed as supporting perceptual narrowing. Infants’ pattern of first looks (i.e., whether infants’ first glance/look was to the sound matched image), however, showed that the number of correct first looks made by the 6-month-olds failed to exceed chance whereas the number of first looks made exceeded chance for the 18- and 24-month-olds (see Fig. 1). Thus the proportion of total looking time showed a pattern of results consistent with perceptual narrowing while infants’ first looks showed a pattern of gradual improvement.

The purpose here is not to challenge whether the proportion of total looking time is an appropriate measure, rather it is to highlight the fact that discrepant conclusions may be reached by virtue of using different but related dependent variables. Moreover, and as highlighted by Bahrick (2002), the use of the first looks, in comparison to proportion of looking time, assesses differences in infants’ attention and processing of the event. Specifically, if infants readily perceive the intersensory correspondence they may initially look to the matching event, but because they quickly attended to and processed the event they may shift their attention to the non-matching display or elsewhere, thus infants’ proportion of total looking to the matching display may not exceed chance. Future research examining
perceptual narrowing, as well as other developmental experiments using either the preferential looking or intermodal matching procedure, may benefit by including both infants’ proportion of looking as well as their frequency of first looks toward the novel or matching event.

Just as different behavioral measures, that is, proportion of looking and first looks, have yielded different patterns of results; neurophysiological studies have also revealed somewhat conflicting patterns of results depending on the time window or neural component being examined. In addition, neurophysiological results are often at odds with the results of behavioral measures. For example, Scott, Shannon, and Nelson (2006) examined the neurophysiological signatures of two groups of 9-month-olds who were to discriminate human or monkey faces. The results showed that 9-month-olds in the monkey face condition exhibited an enhanced response at N290 and P400 (which are precursors to the N170 component for face sensitivity in adults) to familiar compared to unfamiliar monkey faces and thus showing neurophysiological discrimination of monkey faces. These authors also demonstrated that 9-month-olds were able to discriminate frontal compared to profile human faces but not monkey faces within the P400 component. In general these authors conclude that while 9-month-olds typically fail to show behavioral discrimination of monkey faces, they did show neurophysiological discrimination of both human and monkey faces. Importantly, however, they also noted that different neural signatures were evident for monkey and human faces for which this discrepancy is thought to

**FIGURE 1** Upper portion: Mean (SD) proportion of total looking time (PTLT) to the bark congruent and incongruent facial expression at 6, 12, 18, and 24 months of age. Lower portion: Number of infants whose first look for each test trial was directed toward the congruent expression at 6, 12, 18, and 24 months of age. Reprinted from Flom, R., Whipple, H., & Hyde, D. (2009). Infants’ intermodal perception of canine (*Canis familiaris*) faces and vocalizations. *Developmental Psychology, 45*, 1143–1151. Copyright 2009 by American Psychological Association. Reprinted with permission.
reflect the fact that 9-month-olds face processing is becoming more specialized toward human faces.

Just as there are differences between behavioral and neurophysiological experiments of perceptual narrowing, differences have also been observed, including individual differences, depending on the neurological component or time window that is analyzed. For example, and within the context of speech perception, Rivera-Gaxiola, Silva-Pereyra, and Kuhl (2005), have shown individual differences in the neurological components associated with attention and acoustic analysis of native and non-native speech contrasts. In this experiment, Rivera-Gaxiola et al. (2005) followed infants from 7 to 11 months of age and their subsequent discrimination of native and non-native phonetic contrasts using event-related potentials (ERPs). Their results show that at the group level 7-month-olds, but not 11-month-olds, continue to show discrimination of non-native phonetic contrasts during the N250-550 window. In addition, and not surprisingly, improvement was also shown between 7 and 11 months of age for discrimination of native contrasts (see Cheour et al., 1998 for a similar result). Critically, however, the authors noted that when they examined the individual data two separate sub-groups emerged. Specifically, one group of 7-month-olds showed a larger P150-250 response for native and non-native speech contrasts. The same infants, now 11 months of age, showed a significant N250-550 response for the native contrasts but a significant P150-250 response for the non-native speech contrasts. The second group of 7-month-olds showed a significant N250-550 for both the native and non-native speech contrasts and continued to show a stronger or “cleaner” N250-550 response to the native contrasts at 11 months of age and a somewhat less, albeit significant, N250-550 response to the non-native contrasts. Thus the infants in the second group demonstrated a later and more consistent neural signature from 7 to 11 months of age at N250-550. In the first group, however, infants showed more of an “acoustic” rather than “perceptual” level of discrimination (based on their P150-250 response) at 7 months and some of these infants now at 11 months had shifted to a later and negative N250-550 response to native speech contrasts and retained an earlier but positive response to non-native speech contrasts (see also Aaltonen et al., 1987; Massaro & Cohen, 1983). The significance of these results, as noted by (Rivera-Gaxiola et al., 2005, p. 170), is that group ERP data may mask, or underestimate, individual infants’ perception of non-native phonemes and that the neurological correlates associated with phonetic discrimination, in this case for native and non-native speech contrasts, changes at different points over the course of development.

The results of Rivera-Gaxiola et al. (2005) and Scott et al. (2006) raise the question as to (1) whether our behavioral measures are sensitive enough to capture some of the subtleties of perceptual narrowing, (2) whether the absence of behavioral discrimination is sufficient for demonstrating perceptual narrowing, and as noted by Scott et al. (2006) (3) how would the brain detect, or show evidence, of a permanent perceptual “loss”? More generally, while neurophysiological results provide evidence that discrimination often continues during development one must be cautious in the interpretation of group data as infants may show individual differences in how they exhibit perceptual discrimination. Finally, the neurophysiological findings of Rivera-Gaxiola et al. (2005) and Scott et al. (2006) demonstrate that much of early perceptual discrimination and perceptual narrowing is likely based on differences, including individual differences in the development of attention (Cashon & DeNicola, 2011; Werker & Tees, 2005).

Each of these methodological differences, within behavioral and neurophysiological experiments, underscore the need for careful interpretations and suggest that a single dependent measure may not be adequate in examining perceptual narrowing. Finally, caution must also be taken when comparing the results of infants and adults within studies of perceptual narrowing (e.g., adoption/immigration studies examining face/speech perception) as they may differ in the duration, as well as the number of trials participants can complete, and the comparability of metrics such as looking time measures and d-prime or signal detection measures. Future research is needed that directly examines how various methodological factors affect our understanding of perceptual narrowing.

**FUTURE OF PERCEPTUAL NARROWING**

The primary purpose of many, if not most of the early investigations of perceptual narrowing, was to examine how early experience (or a lack thereof) shapes later perceptual development. Specifically, early studies examined when, and in what way, the perceptual systems become attuned to the idiosyncratic experiences of the organism. More recently, and as reviewed above, a growing body of evidence shows greater flexibility of the perceptual system than previously assumed. Similarly, it is likely that over time some perceptual discriminations become more difficult, require extra experience, and may differ in the neurological components reflective of such perceptual discriminations (de Heering et al., 2010; Fair et al., 2012; Pallier et al., 2003; Pascalis et al., 2005; San-
grigoli et al., 2005; Scott & Monesson, 2009). Still, there are also some perceptual properties or features that, over the course of development, can no longer be perceptually discriminated in the absence of the appropriate experience.

Given the dynamic nature of perceptual development and the foregoing review one question is whether the term perceptual narrowing accurately captures the experience-dependent process of perceptual development (see also Maurer & Werker, 2014)? In a related vein Pascalis et al. (2002, p. 1322) question whether perceptual narrowing reflects a “general perceptuo-cognitive tuning apparatus that is not specific to a single modality and that can be described as an experience-expectant system. Alternatively, the concordance in age (in terms of narrowing within speech and within faces) may simply be a developmental coincidence, thus reflecting a modality-specific, experience-dependent process.”

As noted by Pascalis et al. (2002) one possibility is that perceptual narrowing may be characterized by a broad-based, and general, perceptual “tuning” mechanism. If this perspective is correct, then a broader term like “perceptual learning” may better capture the process of perceptual narrowing (Gibson, 1969; Gibson & Pick, 2000). Moreover, it is likely that an organism’s expected, as well as their idiosyncratic, experiences (i.e., experience-expectant and experience-dependent processes) operate in a bi-directional manner with the organism’s prior, as well as current behavioral, and neurophysiological development. Thus the bi-directional transaction between experience and development collectively shapes, that is, attenuates and attunes, the perceptual systems toward those properties and/or attributes most relevant for development. In other words, it is possible that perceptual learning captures the dynamic process of perceptual and attentional attenuation and attunement. Specifically, perceptual learning may reflect “a narrowing down from a vast manifold of information to the minimal, optimal information that specifies the affordance of an event, object, or layout” (Gibson & Pick, 2000, p. 149). Thus just as experience shapes or attunes the perceptual system toward those properties or attributes relevant for development, likewise it also shapes or attenuates the perceptual system away from those properties not relevant for development (see Kuhl, 2004 for examples). Furthermore, and as reviewed above, the attenuation and attunement (i.e., learning) of the perceptual system remains flexible for many attributes or properties throughout much of development. Similarly, if perceptual development is a dynamic and experience based process then one should not be surprised by the somewhat discrepant and often idiosyncratic results as evidenced by Rivera-Gaxiola et al. (2005) and Scott et al. (2006). Critically, however, whether perceptual learning, or any other terminology (e.g., regressive and progressive perceptual development), more accurately and adequately captures what is currently characterized as perceptual narrowing is an open question and in need of continued discussion.

In connection with discussions of taxonomy or terminology, we must take greater care in our descriptions of this perceptual process, particularly when using phrases like the “loss or permanent decline of an ability” or a “reversal” of perceptual narrowing. We should describe what human infants (or any other organism) do and do not do (e.g., discriminate) within specific contexts and conditions rather than arguing for broad based conclusions such as a generalized “ability” or “skill” (see Kagan, 2011 for a similar point). Future research within this domain has begun, and should continue to examine the limits of this perceptual process as well as the mechanisms underlying this process. For instance, what types of experience(s) maintain infants’ discrimination of a specific property? What properties can infants re-learn to perceptually discriminate after a period with which they have failed to show perceptual discrimination? How long does this perceptual plasticity remain and does it generalize to other properties? Other questions include how do the neurophysiological signatures associated with perceptual narrowing or learning change as a function of experience? Is the chronological age of an infant a reasonable proxy for experience? How do changes in infants’ attention and cognition affect this developmental process? Finally, we would be well served by scrutinizing and expanding our methods of examining this perceptual process.

In addition, most of the evidence examining perceptual narrowing captures the behavioral manifestation of this process, yet behaviorally describing this process does not explicitly define the underlying developmental mechanism. Furthermore, and within the current context, the term perceptual narrowing as first used by Pascalis et al. (2002), and its predecessor perceptual reorganization, first used by Werker and Tees (1984a), were meant as descriptions of a behavioral phenomenon and neither terms were meant to define the underlying developmental mechanism. As reviewed above much progress has been made in addressing the phenomenon of perceptual narrowing, including recent research that sheds light on the underlying behavioral processes of perceptual narrowing (e.g., Lewkowicz et al., 2008, 2010). Still, additional research is needed.
that further examines the underlying process and neural correlates of perceptual narrowing.

CONCLUSION

The study of how, and under what conditions, experience shapes perceptual development has a long-standing history within developmental biology and developmental psychology and the results of these studies have contributed greatly to our understanding of development. Given the rapidly growing interest in the area of perceptual narrowing it seems greater clarity and specificity is called for in how we use this term, as well as how we conduct and describe our experiments. In addition, we must continue to examine the specific contexts and circumstances with which perceptual narrowing does and does not occur.

The goal of this paper is not to challenge or negate previous work; rather it is to review evidence of perceptual narrowing as well as review recent research showing flexibility within the context of perceptual narrowing. In light of the research just reviewed, it is likely that perceptual narrowing is too restrictive of a term or description and fails to capture the dynamic nature of early perceptual development. Finally, we must continue to refine our conceptualization of perceptual narrowing, including our methods, as necessary in order to arrive at a more accurate and complete understanding of early perceptual development.

NOTES

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