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Biased relevance filtering in the auditory system: A test of confidence-weighted first-impressions

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ABSTRACT

Although first-impressions are known to impact decision-making and to have prolonged effects on reasoning, it is less well known that the same type of rapidly formed assumptions can explain biases in automatic relevance filtering outside of deliberate behavior. This paper features two studies in which participants have been asked to ignore sequences of sound while focusing attention on a silent movie. The sequences consisted of blocks, each with a high-probability repetition interrupted by rare acoustic deviations (i.e., a sound of different pitch or duration). The probabilities of the two different sounds alternated across the concatenated blocks within the sequence (i.e., short-to-long and long-to-short). The sound probabilities are rapidly and automatically learned for each block and a perceptual inference is formed predicting the most likely characteristics of the upcoming sound. Deviations elicit a prediction-error signal known as mismatch negativity (MMN). Computational models of MMN generally assume that its elicitation is governed by transition statistics that define what sound attributes are most likely to follow the current sound. MMN amplitude reflects prediction confidence, which is derived from the stability of the current transition statistics. However, our prior research showed that MMN amplitude is modulated by a strong first-impression bias that outweighs transition statistics. Here we test the hypothesis that this bias can be attributed to assumptions about predictable vs. unpredictable nature of each tone within the first encountered context, which is weighted by the stability of that context. The results of Study 1 show that this bias is initially prevented if there is no 1:1 mapping between sound attributes and probability, but it returns once the auditory system determines which properties provide the highest predictive value. The results of Study 2 show that confidence in the first-impression bias drops if assumptions about the temporal stability of the transition-statistics are violated. Both studies provide compelling evidence that the auditory system extrapolates patterns on multiple timescales to adjust its response to prediction-errors, while profoundly distorting the effects of transition-statistics by the assumptions formed on the basis of first-impressions.

1. Introduction

It is commonly held that first-impressions may have a lasting effect on our thinking. Such biases are usually attributed to emotional and mental processes and studied within a decision-making framework (Shteingart, Neiman, & Loewenstien, 2013). However, some recent studies in auditory perception have suggested that the effects of first-impressions permeate even lower-level functions, such as the perception of simple meaningless sounds (Todd, Provost, & Cooper, 2011; Todd, Heathcote, Mullens et al., 2014). The current study was designed to test hypotheses about how first-impressions impact on future sound processing. Specifically, we asked how superordinate patterns – the large-scale structure of sound sequences – affect the encoding and elimination of first-impressions.

The assertion that a first-impression may impact auditory perception is based on observations of the mismatch negativity (MMN) component of the auditory evoked potential. (Todd, Provost, & Cooper, 2011; Todd, Provost, Whitson, Cooper, & Heathcote, 2013; Todd, Heathcote, Mullens et al., 2014; Todd, Heathcote, Whitson et al., 2014; Mullens, Provost, Winkler, & Todd, 2014; Mullens, Woodley et al., 2014). MMN is observed when sounds deviate from an established acoustic regularity, such as a repeating sound

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pattern (Näätänen, Gaillard, & Mäntysalo, 1978; for a recent review, see Näätänen, Kujala, & Winkler, 2011). Regularity in a sound sequence leads to the formation of an internal "prediction model" that prepares the auditory system for acoustic input conforming to the extracted regularity (Winkler, 2007). For example, if the sequence contains a repeating sound, the prediction model is represented in reduced responsiveness to the properties of this sound, while the response to a different sound will include a component marking the failure of the prediction model. In a more abstract example, a pattern may not repeat exactly but, for example, consists of sound-pairs that always increment in pitch (lower followed by higher). In this case, the prediction model will reflect the anticipation of a higher-pitched sound following the first sound of a new pair. The MMN amplitude is thought to be tightly coupled to the stability of repetition (Näätänen, Paavilainen, Alho, Reinikainen, & Sams, 1987; Näätänen et al., 2011; Lieder, Daunizeau, Garrido, Friston, & Stephan, 2013) leading to the assumption that MMN to a pattern-deviation will be largest when the repeating pattern is highly stable.

The term "primacy bias" was introduced by Todd et al. (2011); (see also Todd, Heathcote, Mullens et al., 2014; Todd, Heathcote, Whitson et al., 2014; Mullens, Provost et al., 2014; Mullens, Woodley et al., 2014) to explain a clear violation of the assumption that repetition-stability is the sole determinant of the MMN amplitude. The sequences used in these studies consist of two sounds. At the onset of a sequence, one sound is common and repeating and the other is a rare deviation from the repetition. The role of the two sounds is then regularly alternated within the sequence (termed the multi-timescale paradigm; Todd et al., 2011). It has been found that the MMN-amplitudes can only be explained by repetition-stability effects for those segments of the sequence in which the stimulus probabilities match the ones encountered at the onset of the sequence, but not for segments in which the stimulus probabilities have been reversed. We have suggested that primacy bias is due to a first-impression that entails mapping sounds categorically to either "probable and predictable" or "rare and unpredictable" based on how they appeared at the beginning of the sequence (Todd et al., 2011). We have further suggested that confidence in this mapping is weighted by how long this structure remains constant (Todd, Heathcote, Mullens et al., 2014)—that is, the auditory system forms a confidence-weighted first-impression. In two experiments the present article tests the consequences of the confidence-weighted first-impression hypothesis, establishing the prerequisites for acquiring a first-impression and the factors that will prompt a re-evaluation of the initial categorization of sounds.

2. A confidence-weighted first-impression

The MMN component can be observed as additional negativity at fronto-central scalp locations peaking 80–250 ms after the detection of deviation. It is traditionally estimated from a deviant-minus-standard difference waveform generated by subtracting the averaged evoked potentials elicited by the rare deviation and the common repetition, respectively (Kujala, Tervaniemi, & Schröger, 2007). MMN signifies that a prediction (derived from a "prediction model" specifying the most likely sound characteristics and transitions) failed to account for the current input—i.e., a prediction-error was registered and the model requires adjustment (Winkler, Karmos, & Näätänen, 1996; Winkler, 2007; Winkler & Czigler, 2012). Many models of MMN assume that relevance filtering in the auditory system will faithfully reflect the transition statistics present in simple sound sequences (e.g., Wacongne, Changeux, & Dehaene, 2012; Lieder et al., 2013). When a sequence carries a repetitious structure, the auditory system reduces responses to the properties that are predictable and becomes highly sensitive to any pattern deviations (Friston, 2005). MMN amplitude is thought to be proportionate to the accumulated confidence in predictions based on the stability of the repetitious pattern (Winkler, 2007, 2010). In other words, MMN will be largest when confidence in predictions about the current environment is high due to the reliability of the prediction-model. Conversely, MMN will be smaller when prediction errors are more frequent.

The results from the multi-timescale paradigm (see Fig. 1), contradict the notion that MMN amplitude to pattern deviations will obey a simple function of transition statistics and pattern stability. Sequences in the version of the paradigm we have tested several times contain only two types of sounds and these alternate roles as a repeating "standard" (highly probable and predictable $p = 0.875$) and pattern "deviant" (rare and unpredictable $p = 0.125$) at different rates (e.g., Todd et al., 2011). For example, in Todd et al. (2013) roles alternated every 160 sounds (or 0.8 min) in the unstable rapidly changing sequence, whereas in the more stable slowly changing sequence the roles alternated every 480 sounds (or 2.4 min). Prediction models update very dynamically (Winkler et al., 1996; Bendixen, Prinz, Horváth, Trujillo-Barreto, & Schröger, 2008). In the multi-timescale sequence this means that the sound that is first rare and elicits MMN will rapidly become the new standard when it starts repeating (i.e., when roles reverse). Once the new standard is established, rare presentations of the former standard can be recognised as deviations from this new prediction model and they start eliciting MMN. Accordingly, significant MMN is observed for all deviant/standard combinations in the multi-timescale paradigm (Todd et al., 2011, 2013; Todd, Heathcote, Mullens et al., 2014; Todd, Heathcote, Whitson et al., 2014; Mullens, Provost et al., 2014; Mullens, Woodley et al., 2014). On the basis of the previously observed effects of pattern stability on MMN (Sussman & Winkler, 2001), MMN amplitude should be larger in the stable than in the unstable sequences, because the system can accumulate information about stability over longer periods of time. *Primacy bias* refers to the observation that this assumption has only been found to hold for MMN elicited in the stimulus blocks (segments concatenated to form a stimulus sequence) that matched the standard/deviant combination appearing in the first stimulus block of the experimental session (Todd et al., 2011). It did not apply to MMN elicited to the deviants in role-reversal blocks where the first-deviant became the standard and the first standard became the deviant. MMN in these role-reversal blocks has either been equal or even smaller in amplitude in the stable (slower changing) than in the unstable (more rapidly changing) sequences.

The notion that a *confidence-weighted first-impression* might account for this phenomenon derives from examining the pattern of primacy bias across studies. Here we refer to the confidence-weighted first-impression as the hypothesised cause of changes in MMN modulation and the primacy bias as the observed effect of this impression. Firstly, the bias has been observed to occur for several different standard/deviant combinations. It has been detected in sequences where the first-deviant is a long duration sound and also in those in which the first-deviant is a short duration sound (Todd et al., 2013). It is also present in sequences in which the two stimuli differ in pitch (Todd, Heathcote, Whitson et al., 2014) or in phonemic properties (Mullens, Provost et al., 2014). In each case, MMN to the first encountered deviant stimulus (termed "first-deviant") shows significantly more modulation by pattern stability within sequences (i.e., sequence stability, larger when stability is high), than MMN to the stimulus encountered as deviant in the role-reversed blocks ("second-deviant"). The latter MMN is either modulated less, not at all, or even in the reverse direction. These results imply that the bias is an order (sequence structure) driven phenomenon as opposed to an effect of stimulus parameters, and that the content of the first-impression is linked to the sound probabilities at sequence onset.