Research report

Automatic detection of the duration of visual static and dynamic stimuli

Szonya Durant [a,*], István Sulykos [b,c], István Czigler [b,c]

[a] Royal Holloway, University of London, UK
[b] Institute of Cognitive Neuroscience, Research Centre for Natural Sciences, Hungarian Academy of Science, Hungary
[c] Eötvös Loránd University, Budapest, Hungary

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ABSTRACT

The perception of the passing of time is fundamental to conscious experience. The duration of a sensory stimulus is one of its defining attributes, but it is not clear how this is encoded in the brain. This work explores whether the duration of a visual stimulus is an attribute that the brain can automatically adapt to and use to predict future stimulus durations. Visual mismatch negativity (vMMN) is an ERP component elicited, even when the stimuli are unattended, when an 'unexpected' visual stimulus appears amongst a series of expected stimuli in an 'oddball' paradigm. As such vMMN has been suggested to show that the violation of a pattern in a sequence has been automatically detected. To date, vMMN has only been measured to differences in the visual durations of static on/off stimuli, placed near to the centre of the visual field. Our study measures vMMN to test whether duration is encoded automatically for static stimuli against a blank background and moving stimuli against a static background, whilst attention is directed to a different spatial location using a continuous, attention demanding task. VMMN elicited in response to the shorter duration for both stimuli shows that the brain detects the differences of duration even in the absence of focussed spatial attention. For the motion stimulus a larger difference in duration was needed. We conclude that duration is encoded automatically in the visual cortex and is an attribute that can be adapted to, and form the basis of predictions.

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1. Introduction

Duration is considered a fundamental sensory attribute, a building block of our conscious experience, yet the encoding of duration remains little understood. Every sensory signal also marks the duration of an event. In this article we are interested in duration as a perceptual attribute, i.e. relatively short durations (<1s), which we assume to be less reliant on conscious memory. This time scale is often referred to as interval timing (Buhusi and Meck, 2005).

The question we ask is whether the duration of visual stimuli is a basic visual feature encoded explicitly, or only extracted when required by the task demand. It is not clear whether the perceived duration of stimuli is encoded automatically as a property of the stimulus or whether duration rides on top of the sensory signal to be deduced only by some later mechanism when, and if, required. Some behavioural work suggests that some aspects of duration are encoded within the sensory cortex, perhaps surprisingly even in early visual cortex, where retinal location specific adaptation of perceived duration can be induced by rapid visual flicker (Johnston et al., 2006).

Many other brain areas are implicated in duration perception. Ramping signals exist in the parietal cortex (Janssen and Shadlen, 2005), attention to time activates the supplementary motor area (Coull, 2004) and damage to the cerebellum impairs time perception ability Ivry and Spencer (2004). In short, many areas appear to encode durations under certain task conditions, but it is not clear to what extent this is explicit coding of duration or instead a by-product of motor preparation and/or attention. Lewis and Miall (2003) summarised research on automatic versus cognitively controlled duration perception. They admit that the primary cortical activity found in association with automatic timing, might simply be due to sensory stimuli and motor responses and it is difficult to specify how much of this is duration specific.

The most established models for duration perception make recourse to a pacemaker/accumulator type clock model, where a central pacemaker emits pulses that are counted by an accumulator to give a measure of time elapsed (Treisman, 1963; Church and Meck, 2003; Wearden, 2003). In this framework the question is – what is it that triggers the start of this accumulation? Often this 'switch' is thought to be gated by attention (Treisman et al., 1990). Whilst attention clearly modulates perceived duration

* Corresponding author at: Dept. of Psychology, Royal Holloway, University of London, Egham, Surrey TW20 0EX, UK.

E-mail address: szonya.durant@rhul.ac.uk (S. Durant).

(e.g. Brown et al., 1992), it is not clear whether the encoding of duration happens outside the window of attention. The question remains as to how stimuli are selected to be temporally tracked by the accumulator. Models that avoid the pacemaker approach suggest that the durations of multiple events can be implicitly measured (Hopson, 2003), but it is not clear if such implicit coding can lead to the automatic detection of patterns of duration.

Another way to approach this question is to suggest that if duration is a property that is encoded automatically, the mechanisms selective for specific durations should undergo adaptation, after repeated stimulation by the stimulus they are selective for - a commonly observed phenomenon referred to as "the psychophysicist's electrode" and a similar phenomenon termed repetition suppression is used in fMRI. Psychophysical (Heron et al., 2012) and MRI studies (Hayashi et al., 2015) suggest that duration is a stimulus property that can be adapted to, but questions remain, as both these paradigms involve attended visual stimuli signalled by strong onset and offset signals. It is still not clear if adaptation is an automatic response to repeated durations over time and can be used to alter the encoding of future durations.

In a similar vein, asking if repeated durations can be detected automatically as an expected visual property, one can measure MMN (mismatch negativity). Visual MMN (vMMN) is an evoked response potential (ERP) signal found in response to an unexpected stimulus that follows a series of more predictable stimuli. As such it is thought to be a marker of the detection of the violation of a regular pattern that has become encoded on some level (Czigler et al., 2002). Importantly, it emerges even when the pattern of stimuli is not well attended, suggesting that such pattern violations are detected in some sense automatically. So if the same duration stimuli are repeated frequently and an unexpected stimulus of a different duration elicits a MMN response, this suggests that the patterns of duration have been encoded automatically. A wide range of MMN studies of duration perception for sound have demonstrated sensitivity for duration differences in the auditory domain (Kaukoranta et al., 1989; Jacobsen and Schröger, 2003), but MMN activations here occur in central and frontal regions, so it is difficult to ascertain to what extent these are traces of sensory encoding or some more central memory mechanism. Additionally, audition may be expected to be more closely linked with temporal processing (timing is critical for such aspects as musical rhythm and speech perception).

In the visual modality Chen et al. (2010) measured vMMN for the duration of a centrally presented red circle appearing and disappearing against a blank background. They used the standard oddball paradigm, where a sequence of frequently occurring stimuli (standards), is interspersed with the occasional rare stimulus (deviant).The standard stimulus had a 200 ms duration and the deviant stimulus lasted 120 ms and in the control condition the roles of the durations reversed (this is called a reverse control). They also presented tones of the same durations within the same sequences. Participants made a judgement about which duration was presented upon each presentation. They either made the judgement about the visual stimulus or the auditory stimulus. In this way the modality that attention was focussed on was manipulated. Participants were familiarised at the start with the two possible durations. The authors only reported the ERP response to the short stimulus, calculating MMN as the difference in response in the control condition (when it was the standard stimulus) from the response in the main experimental condition (when it was the deviant stimulus). Peak vMMN was found at 216 ms latency, i.e., 96msec from the onset of differences between the two visual stimuli. This was found at central and parieto-occipital locations. Interestingly they found that vMMN for the visual duration was modulated by attention (but not auditory MMN), although visual vMMN did still occur when attention was directed towards the auditory stimulus. The inter-trial intervals were 700–1500 ms, relatively long if considering detection of patterns in a perceptual stream without conscious memory.

A further study by Khodanovich et al. (2010) contrasted several different durations using a visual stimulus consisting of on/off flashing L.E.D.s. In the oddball sequence they presented a frequent 200 ms duration flash, interspersed with infrequent 50, 100 and 150 ms flashes. They also presented control sequences in which each of the 50, 100 and 150 ms flashes were presented on their own, repeating uniformly over the sequence. This way they could contrast the same duration under the deviant and control conditions. For the distracted attention condition they played a spoken word auditory stimulus and instructed participants not to attend to the centrally presented visual stimulus. Again, long inter-stimulus intervals (ISI) were used, which varied randomly from 1600 to 2000 ms. They found significant vMMN at right temporal electrode locations, at 200–400 ms from stimulus onset, i.e., 100–150 ms from the onset of differences between stimuli in conditions.

We ask what happens under the condition of a stricter attention control; that is if attention is removed away more from the task-irrelevant stimulus, by using a demanding task that requires continuous visual attention. We present the duration stimuli in the periphery and never make them task relevant or draw the participants' attention to them in any way. This would more fully demonstrate whether visual duration is a property that is encoded automatically. There are some existing vMMN studies of duration perception using a central visual task as distraction, which should provide a more effective control, however some of these studies confound the deviant/standard role by comparing durations of different length directly to each other in different roles (He et al., 2014, Si et al., 2014, Qian et al., 2014). Further recent studies use the reverse control method and measure duration vMMN using on/off black squares either side of the central fixation task (Yang et al., 2016; Qui et al., 2011). They used durations of 50 ms and 100 ms with regular ISIs of 600 ms and 500 ms respectively. Interestingly Yang et al. (2016) find only vMMN to the longer stimulus, 150 to 350 ms from stimulus onset, (so 100–250 ms from the onset of differences between stimuli in conditions), whereas Qui et al. (2011) observe vMMN regardless of decrement or increment at the same latency. Using the very short stimulus duration of 50 ms, it is likely the perceived brightness is different between the two durations according to Bloch's law, stating perceived brightness varies with duration up to around 80 ms (Stévens and Hall, 1966). vMMN has been shown for contrast differences (Stagg et al., 2004) and also for perceived brightness differences (without physical contrast difference) (Sulykos and Czigler, 2014).

We use the timings based on Chen et al. (2010), all durations longer than 80 ms, when Bloch's law is shown to saturate (Stévens and Hall, 1966). Furthermore, we also ask how important it is for duration encoding to use strong visual luminance onset and offset signals such as those generated by the stimuli in the paradigm of Chen et al. (2010). In order to do this we include in our experiment durations signalled by the movement of stimuli on a static background. This way we also test whether the modality of the signal duration alters the mismatch response and also stimulus contrast is kept the same. See Fig. 1 for an illustration of the stimulus. We choose motion as the additional stimulus modality as this is closely linked with temporal processing. For an existing visual object to begin to move is perhaps a more usual occurrence in everyday vision, than for it to appear or vanish. We use a novel motion stimulus that conveys a sense of global motion without any net overall changes in trajectory that could act as a distance measure proxy for time. We also include two different duration