Cognition 128 (2013) 353–362

Contents lists available at SciVerse ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Human visual processing oscillates: Evidence from a classification image technique

Caroline Blais [a,b,*], Martin Arguin [b], Frédéric Gosselin [b,*]

[a] *Département de Psychoéducation et de Psychologie, Université du Québec en Outaouais, Canada*
[b] *Département de Psychologie, Université de Montréal, Canada*

ARTICLE INFO

Article history:
Received 11 May 2011
Revised 16 April 2013
Accepted 28 April 2013

Keywords:
Visual perception
Oscillations
Temporal processing
Visual sampling

ABSTRACT

Recent investigations have proposed that visual information may be sampled in a discrete manner, similarly to the snapshots of a camera, but this hypothesis remains controversial. Moreover, assuming a discrete sampling of information, the properties of this sampling—for instance, the frequency at which it operates, and how it synchronizes with the environment—still need to be clarified. We systematically modulated the signal-to-noise ratio of faces through time and examined how it impacted face identification performance. Altogether, our results support the hypothesis of discrete sampling. Furthermore, they suggest that this mechanism may operate at a rate of about 10–15 Hz and that it is synchronized with the onset of the stimulus.

1. Introduction

When a stimulus is processed by the visual system, the temporal unfolding of visual information extraction may assume different profiles. Despite the fact that we experience a continuous flow of information when we look at the world surrounding us, recent evidence suggests that information is processed in a discrete manner, such that information extraction occurs in distinct moments, in a way similar to the snapshots of a camera (Busch, Dubois, & VanRullen, 2009; Busch & VanRullen, 2010; Landau & Fries, 2012; Mathewson, Fabiani, Gratton, Beck, & Lleras, 2010; Mathewson, Gratton, Fabiani, Beck, & Ro, 2009; Mathewson et al., 2012; Rohenkohl, Cravo, Wyart, & Nobre, 2012; VanRullen & Koch, 2003; VanRullen, Reddy, & Koch, 2005). Here, we propose to test the periodicity of perception by systematically modulating the signal-to-noise ratio of stimuli through time and by examining how it impacts performance. If periodicity is found, this technique will allow us to further characterize its temporal properties.

The empirical evidence in support of the hypothesis of a periodicity in perception started to emerge in the middle of the twentieth century. For instance, it was shown that the visual threshold for detecting a flash of light varies periodically in the few milliseconds preceding the onset of an eye saccade (Latour, 1967); and that the visual threshold for detecting two flashes displayed successively varies periodically as a function of the time interval between them (Latour, 1967). These results were viewed as evidence for discrete information sampling based on the following logic: if, as postulated by the hypothesis of discrete information sampling, little or no information is being processed during some moments, the probability of detecting a brief stimulus should vary as a function of the state of this extraction process. The detection rate should decrease if the stimulus is presented during a "no extraction" state. Likewise, a stimulus with an onset occurring during a "no extraction" state should have to wait until the next extraction state before the processing begins, thus leading to a longer reaction time. As a result, another piece of evidence in support of discrete information processing is that periodicities can be observed in reaction time distributions

* Corresponding authors. Addresses: Département de psychoéducation et de psychologie, Université du Québec en Outaouais, CP 1250, succursale Hull, Gatineau (Québec), Canada J8X 3X7. Tel.: 819-595-3900 #2551; fax: 819-595-2250 (C. Blais), Département de psychologie, Université de Montréal, CP 6128, Succ. Centre-ville, Montréal, QC, Canada H3C 3J7. Tel.: +1 514 343 7550; fax: +1 514 343 5787 (F. Gosselin).

E-mail addresses: caroline.blais@uqo.ca (C. Blais), frederic.gosselin@umontreal.ca (F. Gosselin).

0010-0277/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cognition.2013.04.009

(Dehaene, 1993; Latour, 1967; Venables, 1960; White & Harter, 1969).

A renewal of interest for the hypothesis of discrete perception came from the observation that the wagon-wheel illusion, which consists of perceiving a spoked wheel as rotating differently from its true rotation (i.e. more slowly, stationary, or with a reversed direction of rotation) can occur under continuous illumination (Purves, Paydarfar, & Andrews, 1996; Reddy, Remy, Vayssiere, & VanRullen, 2011; Simpson, Shahani, & Manahilov, 2004; VanRullen, 2006, 2007; VanRullen, Reddy, & Koch, 2006; VanRullen et al., 2005). The wagon-wheel illusion was first observed in movies (i.e. under stroboscopic presentation). The cinematic version of this illusion occurs because the speed at which the camera captures the information differs from the frequency of rotation of the spoked wheel, therefore resulting in temporal aliasing. However, the occurrence of this illusion under continuous illumination cannot be attributed to stimulus presentation constraints. Thus, some researchers have hypothesized that a discrete sampling of information by the visual system could be the basis for the illusion (Andrews & Purves, 2005; Andrews, Purves, Simpson, & VanRullen, 2005; Purves et al., 1996; Rojas, Carmona-Fontaine, López-Calderón, & Aboitiz, 2006; Simpson et al., 2004; VanRullen et al., 2005).

The wagon-wheel illusion under continuous illumination has been used as a tool to determine the properties of information sampling through time. For example, it was shown that the illusion is most prevalent when the wheel rotates at a temporal frequency of about 10 Hz, and it was proposed (based on a motion-energy model) that a system that samples information at a rate of 15 Hz could account for these data (VanRullen et al., 2005). It was also shown that attention was required for the illusion to occur (VanRullen et al., 2005) and that a decrease in power of the 13 Hz band of the EEG power spectrum was correlated with the occurrence of the illusion (VanRullen et al., 2006), suggesting that the discrete mechanism is attention-driven and that 13 Hz cortical oscillations are a potential candidate for this mechanism. However, other studies using different experimental settings have obtained results suggesting a sampling frequency other than 13 Hz (e.g. Busch & VanRullen, 2010; Busch et al., 2009; Dehaene, 1993; Landau & Fries, 2012; Latour, 1967; Mathewson et al., 2009, 2010; VanRullen, Carlson, & Cavanagh, 2007).

An alternative explanation for the wagon-wheel illusion under continuous illumination was proposed, which posits that the illusion is caused by perceptual rivalry (Holcombe, Clifford, Eagleman, & Pakarian, 2005; Kline & Eagleman, 2008; Kline, Holcombe, & Eagleman, 2004, 2006). Due to the debate regarding the origin—perceptual rivalry vs. discrete sampling—of the illusion, our understanding of the temporal properties of visual information sampling would likely benefit from using a method different from that of the wagon-wheel illusion paradigm. Furthermore, because the wagon-wheel illusion principally recruits motion perception mechanisms, the properties of the information sampling of other domains of vision remain to be examined. Hence, supporting evidence for perceptual oscillations came from studies demonstrating that the visual system can be trained, using a rhythmic stimulation, to become more sensitive to stimuli presented in phase with this rhythmic stimulation (Lakatos, Karmos, Mehta, Ulbert, & Scroeder, 2008; Mathewson et al., 2010, 2012; see also Jones, Moynihan, MacKenzie, & Puente, 2002 for a similar phenomenon in audition). Moreover, it was shown that the probability that a stimulus is detected or reaches consciousness is modulated by the phase of the ongoing brain oscillations in low frequency rhythms (Busch & VanRullen, 2010; Busch et al., 2009; Lakatos et al., 2008; Mathewson et al., 2009, 2012). Rohenkohl et al. (2012) have also shown that the improvement in detecting stimuli that are in phase with a rhythmic stimulation occurs via a contrast gain. These observations support the idea that perception is discrete and that the state of the extraction process may determine whether a stimulus is perceived or not.

If perception is indeed discrete, its properties remain to be clarified. For example, it was proposed that a sampling occurring at a rate of around 13–15 Hz (VanRullen et al., 2005, 2006) could be related to the occurrence of the wagon-wheel illusion under continuous light, and perceptual modulations at a rate of around 7–10 Hz have been observed in detection tasks (Busch & VanRullen, 2010; Busch et al., 2009; Landau & Fries, 2012; Mathewson et al., 2009). Does that mean that the sampling frequency varies as a function of the kind of visual processing required by the task? Relatedly, does this information sampling synchronize with the visual stimulation and if so, how? For example, is the sampling resetting its phase at the beginning of each trial in a visual perceptual experiment (i.e. with stimulus onset)? Or is the sampling evolving without synchronizing with the external world, as a passive ongoing oscillation (i.e. random)? Synchronization with the stimulation is more consistent with the periodicities observed in reaction time distributions as well as in the visual threshold preceding the onset of an eye saccade. Nevertheless, how the information sampling synchronizes with the external word remains unclear.

We propose an alternative experimental approach in order to address these questions. The method consists of systematically varying the signal-to-noise ratio of stimuli through time while maintaining stimuli energy constant and examining how different temporal profiles of signal-to-noise ratio impact performance. If perception is indeed discrete, the greater the overlap between the SNR's profile and the observer's information processing profile, the better the performance should be.

The method that we propose is essentially a classification image technique (e.g. Eckstein & Ahumada, 2002; Gosselin & Schyns, 2004). Classification image techniques have been used to probe time before, but never to specifically verify the presence of periodicities in information processing (e.g. Blais et al., 2009; Fiset et al., 2009; Gold & Shubel, 2006; Neri & Heeger, 2002; Neri & Levi, 2008; Vinette, Gosselin, & Schyns, 2004). For instance, Vinette, Gosselin and Schyns (2004) used temporal classification images to reveal the time course of visual features utilization in a face identification task. On each trial, different facial areas were selected and rendered visible while the rest of the face was hidden behind a gray mask. The visibility of the facial areas also varied through time, so that different