Clinical Neurophysiology 125 (2014) 1995–2006

Contents lists available at ScienceDirect

Clinical Neurophysiology

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

Sequential processing in the equiprobable auditory Go/NoGo task: Children vs. adults

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ARTICLE INFO

Article history:
Accepted 13 February 2014
Available online 28 February 2014

Keywords:
Children
Adults
ERPs
Equiprobable Go/NoGo paradigm
Principal Components Analysis (PCA)
Exact Low Resolution Electromagnetic Tomography (eLORETA)

HIGHLIGHTS

- Some early and late ERP components show similarities, but Go/NoGo P2 and N2 effects differ with age.
- This indicates that aspects of stimulus categorisation differ between children and adults.
- Subsequent processing reflected in P3 and later components is similar.

ABSTRACT

Objective: To compare sequential processing in the unwarned auditory equiprobable Go/NoGo task in children and adults, in the context of a recently developed adult schema.
Methods: Adult and child samples completed an equiprobable auditory Go/NoGo task while EEG was recorded from 19 channels. Go and NoGo ERPs were decomposed using unrestricted Varimax-rotated PCAs for the groups separately, and in combination. The separate adult and child components were compared using the Congruence Coefficient. Brain sources of each assessed component were examined using eLORETA.
Results: Corresponding adult/child components were tentatively identified: two N1 subcomponents (N1-1, PN) and P2, followed by N2, P3 (separate P3a/P3b in children), the classic Slow Wave (SW), and a diffuse Late Positivity (LP). While early and late components showed similarities, the intermediate P2 and N2 differed substantially in their stimulus effects.
Conclusions: Aspects of "Go" vs. "NoGo" categorisation differ between adults and children, but subsequent processing reflected in the different Go/NoGo P3 components, and their sequellae, are similar.
Significance: This is the first detailed examination of child responses in this paradigm. The tested schema appears relatively robust in adults, and the child results may aid our understanding of developmental aspects of cognitive processing in normal and atypical individuals.

1. Introduction

The equiprobable auditory Go/NoGo task, sometimes called a 50% auditory oddball task (Barry et al., 2000), is at the mid-point between traditional Go/NoGo tasks (with Go probability > NoGo probability) and the traditional oddball task (with Target probability < NonTarget probability). It generates ERPs that share features of the auditory oddball: sequential P1, N1, P2, N2, and P3 components, followed by the posterior-positive/anterior-negative classic Slow Wave (SW). Overall, the equiprobable Go ERPs appear similar to reduced oddball target ERPs, and NoGo ERPs appear similar to enhanced oddball standard ERPs (Duncan-Johnson and Donchin, 1977; Johnson, 1986), respectively. These ERPs also resemble in morphology those of the traditional Go/NoGo task, although as expected, the substantial NoGo N2 thought to represent inhibition or response conflict (Smith et al., 2013), is less pronounced in the equiprobable task. As in many other Go/NoGo tasks, as well as the oddball, P3 to the Go/target is larger and more parietal than that to the NoGo/standard. We follow Barry and Rushby (2006) who identified these P3 sub-components in this paradigm as P3b and P3a, respectively, as is generally compatible with the wider literature (e.g., Dien et al., 2004; Polich, 2007).

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http://dx.doi.org/10.1016/j.clinph.2014.02.018
1388-2457/

We have been interested in the unwarned equiprobable auditory Go/NoGo task for a number of years; specifically, it is the unique feature of equal stimulus presentations involving two very different processing chains that interests us. We have utilised this paradigm in brain dynamics studies exploring the genesis of the different ERP profiles for "Go" versus "NoGo" (e.g., Barry, 2009); and to examine the impact of prestimulus EEG on the subsequent ERP components, exploring the effects of *phase* (e.g., in children: Barry and De Blasio, 2012) and *amplitude* (e.g., in adults: De Blasio and Barry, 2013). However, our investigations were limited by the paucity of paradigm-specific processing information in the literature. In general, the expectation in this paradigm is a chain of broadly similar components to both Go and NoGo stimuli, with Go vs. NoGo effects anticipated in the N2 (anterior control-related NoGo N2 (Huster et al., 2013) vs. a more posteriorly negative Go N2 (Folstein and van Petten, 2008)), P3 (anterior NoGo P3a vs. posterior Go P3b (Barry and Rushby, 2006)), and SW components.

In order to clarify the processing chains involved in this paradigm in adults, we recently employed Principal Components Analysis (PCA) to assess the full range of ERP components associated with this task, particularly in regard to the differential (Go vs. NoGo) processing involved (Barry and De Blasio, 2013). In the adult sample, we found evidence of what were identified as an early P1 and N1-3 (Component 3 of the N1; Näätänen and Picton, 1987); these were not assessed due to their small variance. Following these sequentially we identified the N1-1 (Component 1 of the N1; Näätänen and Picton, 1987), Processing Negativity (PN; Näätänen and Picton, 1987), P2, N2, P3, classic SW, and a novel component we labelled as the "Late Positivity" (LP). Interestingly, Go vs. NoGo differences were found as early as the N1-1. The differential Go vs. NoGo pattern of results prompted the following interpretation of the processing stages and their indicators in this paradigm: N1-1 and PN mark the start of the identification of the characteristics defining Go/NoGo, and further sensory processing is reflected in the P2. Categorisation of the stimulus as "NoGo" results in a frontal N2, fronto-central P3, and an enhanced LP, while categorisation as "Go" is associated with a posterior N2 and P3, and classic SW, representing directed processing related to response preparation and execution. Our interest here was to investigate whether this response pattern could be replicated in an adult sample, and to explore the generality of this processing schema in the developmental context, assessing if it can also be found in children.

Specific information on child ERPs in the unwarned equiprobable auditory Go/NoGo task is minimal. In a study of prestimulus EEG phase effects on child ERP peak amplitudes using this paradigm, Barry and De Blasio (2012) reported a large frontocentral P1, frontocentral N1, centroparietal P2, frontocentral N2, and a P3 that was parietal to Go and central to NoGo. The early components were embedded in a large frontal negativity, similar to that found in children by Holcomb et al. (1986) using auditory paradigms. They had reported a large early broad negativity (100–300 ms) to targets and non-targets in an oddball task, that appeared to overlap N1, P2 and N2 components, and identified a late frontal negativity (350–700 ms) as the Nc common in children (Courchesne, 1977). These data are broadly compatible with child ERP morphology development reported for a 15% auditory oddball (Johnstone et al., 1996), where the reduction in the early broad frontal negativity showed a linear trend from 8 to 17 years. A similar large early frontal negativity, centred on N2, was reported in 10-year olds in a Go/NoGo task with 30% NoGo probability (Johnstone et al., 2005). The later N2 and P3 components were examined in 9-year olds by Jonkman et al. (2003) using a cued continuous performance task variant of the Go/NoGo task with 10% cued Go and cued NoGo trial pairs. They found elevated negativity in the N2 window for children, and this was greater for NoGo than Go. Jonkman et al. interpreted higher false alarm and impulsivity scores, together with the absence of a frontocentral NoGo P3 in children, in terms of a developmental lag in response inhibition. These data also complement the wider developmental literature. For instance, in a study of component amplitude changes from age 7 years to adulthood, Oades et al. (1997) reported developmental increases in N1 and P3, and developmental decreases in N2, together with maturational shifts towards adult topography. However, there are no relevant PCA studies in children.

The aims of this study were fourfold: (1) replicate the sequential processing schema in an adult sample; (2) explore the full range of child ERP components uncovered by the PCA in this paradigm; (3) infer the processing milestones in this paradigm in children; and (4) compare the processing chain between adults and children to provide insight into their developmental/processing differences. Previously we have used Low Resolution Electromagnetic Tomography (LORETA; Pascual-Marqui et al., 1994; Pascual-Marqui, 1999) to determine brain sources for adult P3a and P3b responses from 15 Go and 15 NoGo trials in a comparable auditory paradigm (Barry and Rushby, 2006), and were interested in identifying the sources of these and other components in both adults and children. Here we employed eLORETA (Pascual-Marqui, 2007, 2009), as an adjunct to our usual topographic scalp analysis.

2. Methods

2.1. Participants

The adult group consisted of 18 healthy University of Wollongong students (9 females, 9 males; 17 right-handed) recruited from the School of Psychology. Their mean age was 20.7 (range 18–30) years. The child group consisted of 18 healthy children (9 females, 9 males; 11 right-handed) recruited from the local region via newspaper advertisements. Their mean age was 10.3 (range 9–11) years. Subjects were screened for neurological disorders, head injury, learning disability and psychiatric conditions. All participants were required to abstain from caffeine and other psychoactive substances for at least 4 h prior to the testing session. Participation was voluntary and informed consent was obtained from the volunteer (adult sample), or parent/guardian (child sample), in line with a protocol approved by the joint University of Wollongong/South East Sydney and Illawarra Area Health Service Human Research Ethics Committee.

2.2. Physiological recording

Continuous EEG was recorded from 19 scalp sites (×20,000 gain), using an electrode cap referenced to linked ears; care was taken to balance ear impedances. Vertical and horizontal electrooculograms (EOGs) were also recorded (×5000 gain). Tin electrodes were used for both EEG and EOG recordings, and all impedances were below 5 KΩ. Data from 0.03 to 35 Hz were sampled by a 16 bit A/D system (AMLAB II) at 512 Hz, and recorded for later off-line analysis.

2.3. Task and procedure

An unwarned equiprobable auditory Go/NoGo task was used. Stimuli were presented in blocks of 150 tones (50 ms duration, 5 ms rise/fall times), binaurally via headphones at 60 dB SPL, with a fixed stimulus onset asynchrony of 1100 ms. Half the tones were 1000 Hz, and half 1500 Hz, and these were presented in random order to avoid any consistent sequence effects between subjects. Adult participants received two stimulus blocks and, in anticipation of the greater loss of trials common in child recordings through increased artefact and lower performance levels, children received three blocks. Participants were instructed to press a