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Multimodal analysis of startle type responses

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ABSTRACT

Background and objective: This article presents a multimodal analysis of startle type responses using a variety of physiological, facial, and speech features. These multimodal components of the startle type response reflect complex brain–body reactions to a sudden and intense stimulus. Additionally, the proposed multimodal evaluation of reflexive and emotional reactions associated with the startle eliciting stimuli and underlying neural networks and pathways could be applied in diagnostics of different psychiatric and neurological diseases. Different startle type stimuli can be compared in the strength of their elicitation of startle responses, i.e. their potential to activate stress-related neural pathways, underlying biomarkers and corresponding behavioral reactions.

Methods: An innovative method for measuring startle type responses using multimodal stimuli and multimodal feature analysis has been introduced. Individual's multimodal reflexive and emotional expressions during startle type elicitation have been assessed by corresponding physiological, speech and facial features on ten female students of psychology. Different startle eliciting stimuli like noise and airblast probes, as well as a variety of visual and auditory stimuli of different valence and arousal levels, based on International Affective Picture System (IAPS) images and/or sounds from International Affective Digitized Sounds (IADS) database, have been designed and tested. Combined together into more complex startle type stimuli, such composite stimuli can potentiate the evoked response of underlying neural networks, and corresponding neurotransmitters and neuromodulators as well; this is referred to as increased power of response elicitation. The intensity and magnitude of multimodal responses to selected startle type stimuli have been analyzed using effect sizes and medians of dominant multimodal features, i.e. skin conductance, eye blink, head movement, speech fundamental frequency and energy. The significance of the observed effects and comparisons between paradigms were evaluated using one-tailed *t*-tests and ANOVA methods, respectively. Skin conductance response habituation was analyzed using ANOVA and post hoc multiple comparison tests with the Dunn–Šidák correction.

Results: The results revealed specific physiological, facial and vocal reflexive and emotional responses on selected five stimuli paradigms which included: (1) acoustic startle probes, (2) airblasts, (3) IAPS images, (4) IADS sounds, and (5) image-sound-airblast composite stimuli. Overall, composite and airblast paradigms resulted in the largest responses across all

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analyzed features, followed by sound and acoustic startle paradigms, while paradigm using images consistently elicited the smallest responses. In this context, power of response elicitation of the selected stimuli paradigms can be described according to the aggregated magnitude of the participants' multimodal responses. We also observed a habituation effect only in skin conductance response to acoustic startle, airblast and sound paradigms.
Conclusions: This study developed a system for paradigm design and stimuli generation, as well as real-time multimodal signal processing and feature calculation. Experimental paradigms for monitoring individual responses to stressful startle type stimuli were designed in order to compare the response elicitation power across various stimuli. The developed system, applied paradigms and obtained results might be useful in further research for evaluation of individuals' multimodal responses when they are faced with a variety of aversive emotional distractors and stressful situations.

1. Introduction

Startle stimuli represent various sudden and intense events that cause defensive responses, like a quick muscle contraction, activation of various facial and skeletal muscles within a few milliseconds, leading to a whole body reflex that serves to protect the back of the neck and eyes [1]. Three different components of the startle response should be distinguished [2]. First, muscle contractions protect vulnerable structures, like the neck or the eye ball. Beyond this immediate physical protection, a brief surge in activation of the autonomic nervous system (ANS) and endocrine response prepares the individual for a flight-or-fight response. This vegetative component of the startle response is reflected in a number of physiological signals, such as blood pressure [3], heart rate [3], skin conductance [4] and respiration [4]. Finally, ongoing cognitive processes are disrupted and attention is rapidly reoriented to the threatening stimulus [5,6].

Multimodality in startle type stimulation refers to a variety of visual stimuli, like images and video clips, and narratives with high arousal and application-specific associative contexts and semantics, which are superimposed on traditional startle stimuli. Such composite stimuli create more complex multimodal emotion elicitation with relatively high evoked response potentiation, referred to as elicitation power [7]. Such stimulation simultaneously targets several somatosensory cortex regions, including auditory, visual and tactile areas, and results in the broadest activation of different neural networks associated with potential traumatic events and experience. With such comprehensive semantically specific stimuli, a subject's potential deficits regarding his/her cognitive personal appraisal or hidden traumatic associative memories can be better assessed. Multimodality in the startle type response refers to reflexive and emotional reactions which can be captured by characteristic multimodal response signatures, like increased skin conductance, heart rate, contraction of the neck muscles, eye blink and laryngeal reflexive reactions, as well as emotional, cognitive and behavioral responses.

This paper presents an integrated multimodal analysis of responses to startle type stimuli via selected physiological, speech and facial features, unlike previous research works that typically focus on a single modality in combination with standard electromyogram (EMG) measurements of the eye blink startle response via the *orbicularis oculi* muscle. For example, in the physiological modality, Alpers and colleagues have conducted simultaneous analysis of *orbicularis oculi*, heart rate and electrodermal activity [8]. In the speech modality, the fundamental frequency (F_0) startle response analysis was proposed and studied by Sapir and colleagues [9], who compared F_0 to invasive EMG measurements of the laryngeal muscle response. In the facial modality, there have been a few studies of startle responses focused on automated eyelid detection and tracking in high-speed videos [10,11], as well as motion tracking of head and upper-body startle response with comparison to EMG measurements of the *orbicularis oculi* [12]. In comparison with previous papers, startle responses in this paper were analyzed simultaneously via dominantly expressed physiological, speech and facial features, i.e. skin conductance, speech fundamental frequency, speech energy, eye blinks and head movement. Additionally, we have designed and evaluated a series of elicitation paradigms for startle type responses using visual, auditory, or tactile stimuli, as well as their combination, which has not been done previously.

2. The system for multimodal analysis of startle type responses

The concept of the system for generation of various startle type stimuli and multimodal analysis of associated startle type responses by measuring physiological, vocal and facial reactivity is shown in Fig. 1. The system is built around Lenovo S30 Workstation with Intel Xeon Processor E5-2620 v2 (15M Cache, 2.10 GHz), 32 GB of memory, and nVidia Quadro K200D graphics card, running Microsoft Windows 8.1 Pro operating system. Four system displays are related to: a display for supervisor system management, such as stimuli specification and specification of channels for multimodal data acquisition; two displays for stimuli presentation to the participants as well as experimenters; and a display for real-time visualization and tracking of selected multimodal response features like skin conductance, speech energy and fundamental frequency, eye blink, head translation etc. Systems for multimodal data acquisition include: Nexus-10 mark II device with 10 channels including skin conductance,