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Invited paper for the section: Hot Topics in Bio Imaging

[INVITED] Non-intrusive optical imaging of face to probe physiological traits in Autism Spectrum Disorder ☆

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ABSTRACT

Autism Spectrum Disorders (ASD) can impair non-verbal communication including the variety and extent of facial expressions in social and interpersonal communication. These impairments may appear as differential traits in the physiology of facial muscles of an individual with ASD when compared to a typically developing individual. The differential traits in the facial expressions as shown by facial muscle-specific changes (also known as 'facial oddity' for subjects with ASD) may be measured visually. However, this mode of measurement may not discern the subtlety in facial oddity distinctive to ASD. Earlier studies have used intrusive electrophysiological sensors on the facial skin to gauge facial muscle actions from quantitative physiological data. This study demonstrates, for the first time in the literature, novel quantitative measures for facial oddity recognition using non-intrusive facial imaging sensors such as video and 3D optical cameras. An Institutional Review Board (IRB) approved that pilot study has been conducted on a group of individuals consisting of eight participants with ASD and eight typically developing participants in a control group to capture their facial images in response to visual stimuli. The proposed computational techniques and statistical analyses reveal higher mean of actions in the facial muscles of the ASD group versus the control group. The facial muscle-specific evaluation reveals intense yet asymmetric facial responses as facial oddity in participants with ASD. This finding about the facial oddity may objectively define measurable differential markers in the facial expressions of individuals with ASD.

1. Introduction

Autism Spectrum Disorder (ASD) is characterized by core deficits in the areas of social, communication, and behavioral interactions. These deficits may manifest as atypical patterns in an individual's behavior, which may provide useful markers for diagnosing the impairments associated with ASD. The Diagnostic and Statistical Manual (DSM) of mental disorders outlines one of the diagnostic criteria of ASD as impairments in the use of non-verbal cues such as eye-gaze and facial expressions during social interaction [1]. While studies involving atypical patterns of eye-gaze in individuals with ASD have been published in the literature [2–4], few studies have been conducted to examine and characterize the atypical patterns of facial expressions (facial oddity) in individuals with ASD. The facial oddity in individuals with ASD are challenging to quantify and classify as these pattern may appear different from the typical facial expressions of typically developing individuals such as happy, sad, angry, and surprised. Currently, the majority of research studies visually examine the facial expressions of the individuals with ASD using facial image frames [5–7]. The results of some of these studies have reported traces of oddity in the facial expressions of individuals with ASD. However, the findings regarding the atypical patterns of facial expression in individuals with ASD are qualitative and do not provide an objective way to measure such traits in ASD. There have been a few studies which involve quantitative methods to analyze the facial expression using electrophysiological sensors like electromyography (EMG) [8–10]. Unfortunately, EMG sensors are intrusively placed on the facial skin and may potentially inhibit spontaneous facial expressions. Considering the shortcomings of the existing research, this study aims to quantify and characterize the subtle and spontaneous facial expressions of individuals with

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ASD using non-intrusive imaging of the face. Specifically, two non-intrusive optical imaging sensors: a video camera and a 3D optical camera have been employed during a pilot study to capture 2D and 3D facial images of participants in response to visual stimuli, respectively. The 2D and 3D facial images are collected from eight participants with ASD in an ASD group and eight typically developing (TD) participants in a control group. We propose a novel framework to compute the oddity in facial expressions by probing specific facial muscles from 2D and 3D facial images. ANOVA tests are conducted on the extracted features representing the facial physiology in order to find differential traits in the ASD group compared to the control group with TD participants.

The organization of the remaining paper is as follows. Section 2 provides a background literature review relevant to the current study. Section 3 outlines the experimental design for the pilot study and data analysis frameworks for multimodal facial images. Section 4 discusses the results obtained following the data analysis framework for 2D and 3D facial images, respectively. Section 5 provides a general discussion on the results and the paper concludes in Section 6.

2. Background review

Neurodevelopmental disorders may manifest as impairments in facial expressions which can affect an individual's social and interpersonal communication skills. The impairments in facial expressions have been studied among individuals with Alzheimer's disease using retrospective visual analysis of facial images [11]. In one of the earliest works, Adrien et al. conduct a retrospective analysis on home videos of children with ASD acquired from 11 families [12]. Their study, based on visual investigation, reveals differences in eye-contact and facial expressions between children with and without ASD. Therefore, atypical eye-gaze and facial expressions have been common targets to diagnose impairments in an individual's non-verbal communication skills. While physicians use their visual observation and expertise during the diagnostic process, most of the research studies on these targets employ naïve human coders who qualitatively rate the expressions of individuals with ASD from facial images. Volker et al. employ naïve human coders to evaluate the performance of participants with ASD in imitating different facial expressions [7]. Their qualitative assessment reports awkward manifestation of facial expressions in subjects with ASD. Stel et al. use an audio-visual stimulus to elicit facial expressions in subjects with ASD and employ naïve human coders to evaluate the expressions from facial images [5]. In a similar retrospective analysis of facial images of individuals with ASD, Faso et al. report more intense presence of facial expressions when compared to a typically developing control group. However, such intense facial expression is qualitatively reported to be less natural than that perceived in TD participants. The lack of natural traits in facial expression has been termed as odd facial expression, and such oddity may be one of the differential markers of impairment in individuals with ASD.

Although the human eye can perceive an emotion underlying a typical facial expression, neurodevelopmental disorders (e.g. ASD, Alzheimer's, Schizophrenia etc.) may impair the facial expressions resulting in facial muscle actions that are too subtle and ambiguous to trace visually. This necessitates a system capable of providing quantitative evaluation of the subtle facial expressions to assist the physician with objective diagnostic information. Electromyography (EMG) sensors have been traditionally employed on the face to measure the induced emotion from the physiology of face in subjects with ASD [9,8,10,13]. However, these studies involve tedious and intrusive procedures for placing EMG electrodes on the facial skin of the participants with ASD. Since half of the ASD population is known to have anxiety and fear of novel experiences, as well as tactile defensiveness [14], such intrusive administration of electrodes may inhibit or alter the spontaneous facial response. The use of wearable devices and intrusive sensors in individuals with ASD is also discouraged in a recent study [15]. Conversely, non-intrusive optical sensors with computer vision-based quantitative analysis have been employed as more objective and efficient tools in behavioral studies with neurodevelopmental disorders [16,15].

Hamm et al. videotape the face of individuals with Schizophrenia while the individuals attempt to imitate target facial expressions. Recently, a 3D optical camera is employed to analyze the facial morphology of participants with ASD [17,18]. However, spontaneous facial expressions are often challenging to evaluate and none of these works propose non-intrusive quantitative method for facial oddity recognition in ASD. In this paper, we propose a novel computational framework to investigate impairments in the spontaneous facial expressions from both 2D and 3D imaging data. We derive intensity and asymmetry related attributes of several distinct facial muscles to characterize the oddity in the facial expressions.

3. Experimental design and data analysis framework

This section describes the experimental design for data collection and the framework for analyzing the collected multimodal facial imaging data.

3.1. Experimental design

This section discusses the experimental design and protocol to collect video data as 2D facial image frames and 3D facial point cloud data from two groups of participants.

3.1.1. Participants

The proposed study protocol involving human participants is approved by both Institutional Review Boards (IRBs) at Old Dominion University (ODU) and Eastern Virginia Medical School (EVMS). Following the protocol, human participants, between the ages of 7 and 20-years-old, are recruited and placed into one of the two groups. The ASD group consists of eight participants diagnosed with ASD and an average age of 13 ± 4.4 years. A total of eight typically developing participants without diagnosis of any disorder are recruited under the control group with an average age of 16 ± 4.1 years. A phone screening is conducted following the inclusion and exclusion criteria in the protocol in order to determine the eligibility of a potential participant. Once a participant is found eligible, the participant and the parent of the participant sign informed consent and assent forms which briefly outline the goals and procedures related to the study.

3.1.2. Materials

A hardware-software system is developed to automate and synchronize the procedures and tasks in the study. The system includes a 68" multimedia TV to display the visual stimulus. Two non-intrusive facial imaging sensors: a video camera and a 3D optical camera are used in this study to capture the facial images of the participant in response to the visual stimulus. A Sony EVI-D70 color camera is used as the video camera, whereas a state-of-the-art 3D facial imaging sensor, 3dMD (www.3dmd.com), is used to capture the 3D facial point cloud data. The cameras are calibrated and positioned to capture the full face without interfering with the line of sight of the participant as shown in Fig. 1 (a).