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Visual Attention in Schizophrenia: Eye Contact and Gaze Aversion during Clinical Interactions

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***Abstract*—Many of the essential clues to the psychiatric condition of an individual lie within the nonverbal and communicative behavior patterns they express during social interactions. Unfortunately, these behaviors are particularly difficult to assess subjectively in a time-constrained environment, to which clinicians are often limited in realistic settings. The present analysis examines quantified patterns of gaze aversion across a set of persons recently admitted to an inpatient psychotic disorder unit at a major psychiatric hospital. These patterns are used to inform the development of discriminative models with the task of predicting schizophrenic symptom severity from both a typological and a dimensional assessment perspective. The results expose a novel set of gaze aversion behaviors distinguishing between positive subtype schizophrenia, characterized by excessive behaviors such as hallucinations and grandiosity, and negative subtype schizophrenia, characterized by diminished behaviors such as blunted affect and emotional withdrawal. The predictive models constitute a significant step toward the development of automated tools to aid medical professionals in the diagnosis of psychotic disorders.**

1. Introduction

When assessing the psychiatric condition of an individual, medical professionals often rely on a subjective assessment of abnormality in nonverbal and communicative behaviors during clinical interviews and day-to-day interactions. Although expert clinicians have a lifetime of experience and knowledge from which to draw a diagnosis, accurate judgment of individual cases is often inhibited by time constraints, clinician fatigue, or merely the human inability to judge every dimension of a person's condition at once. These limitations can interfere with determining the most accurate and timely diagnosis, and by extension the most effective plan of treatment.

One approach to addressing this challenge is to augment the assessment of these medical professionals with tools that can provide objective, automated analysis of a person's behaviors during these focused interactions. These systems would be capable of evaluating behavior patterns with respect to previously collected data of the same individual (perhaps despite changing clinicians), in addition to the information gained from a wider demographic set of persons carrying similar diagnoses. Such a tool could offer more detailed insight into a person's psychiatric condition, allowing the attending clinician to reach a better-informed diagnosis.

In everyday interaction, eye contact is widely considered to be an important signifier of aggression, social rapport, confidence, or interest; on the other hand, the lack of eye contact is often considered an indicator of respect, submissiveness, or even anxiety [1]. As a result, abnormal patterns in eye contact and gaze aversion behaviors are often adopted as significant indicators of psychiatric disorders [2]. Unusual behavior in this space is often a critical indicator of psychiatric illness, most notably in anxiety, depression, and cases of high suicidality [3], [4].

In this paper, we present a detailed investigation of eye gaze behaviors for patients with schizophrenic symptoms. Our analysis focuses on identifying behavior markers differentiating two subtypes of schizophrenia: positive subtype and negative subtype [5]. These subtypes of schizophrenia have been shown to respond differently to a variety of treatment plans [6] and exhibit different predispositions to comorbid conditions [7]. These findings motivate our analysis since they suggest that correct identification of schizophrenic subtype is critical to determining the appropriate course of treatment for a given individual. We analyze eye gaze patterns in the context of the patient's facial expressions as well as the dialogue cues from the clinician. In the later part of this paper, our detailed analysis will inform the development of predictive models for schizophrenic

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subtypes (i.e., typological assessment) and for continuous symptom severity (i.e., dimensional assessment).

2. Related Work

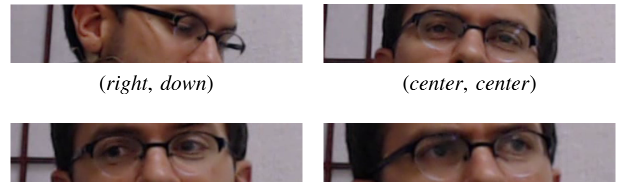
Many psychiatric disorders cause disruption in the normal function of nonverbal or communicative behaviors of an individual [3], [8]. In particular, multiple studies have suggested the importance of identifying gaze aversion in depression and cases of high suicidality; persons with depression are suggested to fixate more frequently [8] and maintain significantly less eye contact when speaking with an interviewer [4] than those without. An avoidance of eye contact has also been seen in individuals diagnosed with other adverse clinical states, such as attention deficit disorder or autism [9].

Some studies have suggested particular differences in gaze behavior in individuals diagnosed with schizophrenia. Rutter suggested that many of these individuals are behaviorally indistinguishable from the general population during conversations of no personal importance, but display markedly abnormal gaze aversion patterns when asked to speak about personal matters [10]. Bergman et al. supported this finding, and suggested that in these afflicted individuals, much of the nonverbal behavior expressed does not synchronize with the verbal utterances [3]. Interestingly, in this study a lack of eye contact was not only observed in the case of the diagnosed person, but in the interviewing clinician as well. Laing suggests that persons diagnosed with schizophrenia may feel particularly vulnerable or exposed under the gaze of others, and may actively avoid eye contact as a result [11]. The present analysis uses this to inform 'categories' of interview questions (see Section 3.2).

Our work examines a variety of gaze aversion behaviors with respect to an individual's results on a clinical inventory of schizophrenic symptoms. Section 3 continues with a detailed description of the interview dataset and the various feature extractions performed upon it. Section 4 describes a set of hypothesis-driven experiments, which informed a predictive analysis described in Section 5. We interpret some of the significant features identified in Section 6. The report concludes with a brief overview and some thoughts toward future directions in Section 7.

3. Clinical Interview Dataset

The dataset examined consists of a series of clinical interviews with adult individuals recently admitted to an inpatient psychotic disorder unit at McLean Hospital, a major psychiatric facility. Video and audio recordings were collected from 21 unique participants (six of whom were female). Each session involved a semi-structured clinical interview between the admitted individual and a clinician, lasting approximately 10–15 minutes each. The interview script was modeled upon existing everyday clinical interactions designed to elicit reactions that may be illustrative of the psychiatric condition of the individual.[1] A list of interview questions is presented in Table 1.



(*right*, *down*) (*center*, *center*)

(*left*, *down*) (*right*, *up*)

Figure 1. An example set of annotated gaze direction labels for sample video frames.

Following the conclusion of each interview, the participant was administered a series of clinical scales, including the Positive and Negative Syndrome Scale (PANSS) [5], a scale used for measuring schizophrenic symptom severity. PANSS involves seven-point ratings of 30 symptoms across three dimensions: *positive symptoms*, involving behaviors in excess or distortion of normal function, *negative symptoms*, involving behaviors diminished or suppressed below normal function, and *general psychiatric symptoms*, involving items that cannot be linked decisively to either syndrome. Items from the Positive and Negative scales are listed and described in Table 2.

Participants are grouped by their PANSS *composite score*, defined as the difference between the positive and negative symptom scores [5]. Participants with a composite score above zero are classified as having *positive subtype* schizophrenia, whereas those below or equal to zero were classified as having *negative subtype* schizophrenia. Twelve of the participants are classified as expressing positive subtype schizophrenic symptoms, and nine are classified as expressing negative subtype. The average Positive Scale score in the present sample is $M = 17.48$ ($SD = 8.09$) and Negative Scale $M = 13.95$ ($SD = 3.92$), both in a possible range of 7 to 49; the average composite score is $M = 3.52$ ($SD = 9.35$), in a possible range of -42 to 42.

3.1. Gaze Aversion Annotation

Each session video was manually annotated for gaze behavior. This annotation task was conducted in two stages: annotation of lateral gaze direction and annotation of vertical gaze direction. Lateral gaze direction was manually classified into *left*, *center*, or *right*; similarly, vertical direction into *up*, *center*, or *down*. Note that an annotation of (*center*, *center*) would indicate gaze at the interviewing clinician and *left* and *right* are directions from the point of view of the interviewing clinician. When eye gaze direction was conflated with head gaze direction, the 'absolute' direction of aversion was taken. For an illustration of sample labels from this annotation scheme, see Figure 1.

1. Although participants varied in previous exposure to similar interactions, this diversity is reflective of the larger population, and we believe that this strengthens the applicability of this analysis.

TABLE 1. CLASSIFICATION OF INTERVIEW PROTOCOL ITEMS INTO INTROSPECTIVE QUESTIONS AND EXTROSPECTIVE QUESTIONS.

Introspective Questions
Has anything in particular been on your mind?
What are your goals for the hospitalization?
How is your mood/spirits?
How is your thinking/focus?
How is your self-confidence compared to how it usually is?
What changes do you observe since you were hospitalized?

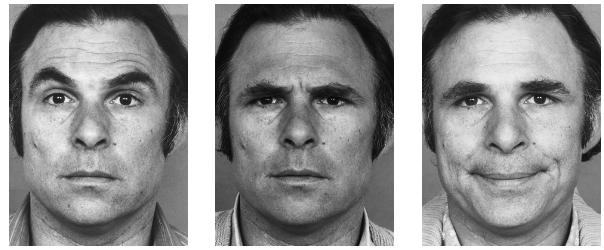
Extrospective Questions
What brought you into the hospital?
What has the team here been helping you with?
Would you say that they are doing a good job?
How have people been treating you?
How is the food?
How is your energy?
How have you been sleeping?

To evaluate the reliability of this annotation scheme, a second annotator repeated this procedure on eight sessions (approximately 38% of the dataset). Each session was segmented by the tenth of a second, and inter-annotator agreement was calculated based on classification into each of the three directional states for each dimension. This resulted in a Krippendorff's alpha coefficient of $\alpha = 0.89$ for lateral movement and $\alpha = 0.76$ for vertical movement, each of which exceeds the usual threshold for a 'reliable' level of agreement [12].

3.2. Dialogue Annotations

Interview items were grouped into two distinct categories: *introspective questions*, in which the participant is asked to examine their thoughts, feelings, or mental state, and *extrospective questions*, in which the participant is asked to describe the state of their environment. Inter-annotator agreement across four independent annotators achieved a Krippendorff's alpha coefficient of $\alpha = 0.85$, a 'reliable' level of agreement [12]. This classification is presented in Table 1.

Annotation of interview dialogue involved selection of the moment at which each question segment began, accurate to the tenth of a second, as well as the classification of the question itself into one of thirteen questions types (see Table 1). In order to evaluate inter-annotator agreement, a second annotator repeated this procedure on five sessions (approximately 24% of the dataset). On average, there was a difference of 1.2 seconds regarding annotation of the start of a question. There were two instances of 'missed' question annotations and one instance of disagreement on question classification, out of a total 48.



(a) AU2 OUTER BROW RAISER (b) AU4 BROW LOWERER (c) AU14 DIMPLER

Figure 2. An illustration of the subset of facial action units used in the present analysis [15].

3.3. Facial Expression Feature Extraction

Facial expression for the purpose of the current analysis is defined in terms of the Facial Action Coding System (FACS), a procedure designed to systematically describe facial expression via individual muscle movements [13]. Video recordings of both clinician and participant were collected at a resolution of 1280×960 pixels at 30 frames per second. Facial action unit intensities were extracted from these videos using OpenFace, a state-of-the-art open-source facial behavior analysis toolkit [14]. After processing with OpenFace, each frame of the video receives an intensity score $s_i \in [0, 5]$ for each of 17 facial action units, four of which are used in the present analysis. Frames with less than 70% confidence in the facial landmark detection results (often due to extreme head pose, rapid motion, or occlusion) were discarded. This threshold resulted in elimination of approximately 16% of the recorded video frames. The three facial action units most prominent in the present analysis are illustrated in Figure 2.

4. Statistical Analysis

Initial examination of the recorded interviews resulted in a number of qualitative observations, which informed the definition of hypotheses detailed in the following subsections. Each of these hypotheses were compared using the appropriate statistical models. Tests for normality and homoscedascity were performed before each test, and all reported p-values have been corrected using the Benjamini-Hochberg procedure for controlling the family-wise error rate within each hypothesis group. In Section 4.1, we consider overall differences in aversion behavior. Section 4.2 studies differences when contextualized within dialogue events. Section 4.3 studies the interactions with facial expressions.

4.1. Aversion

The first set of hypotheses tested involved general trends in gaze aversion behaviors between individuals expressing positive and negative subtype schizophrenia.

TABLE 2. ENUMERATION AND BRIEF DESCRIPTION OF ITEMS CONTAINED IN THE PANSS POSITIVE AND NEGATIVE SCALES [5].

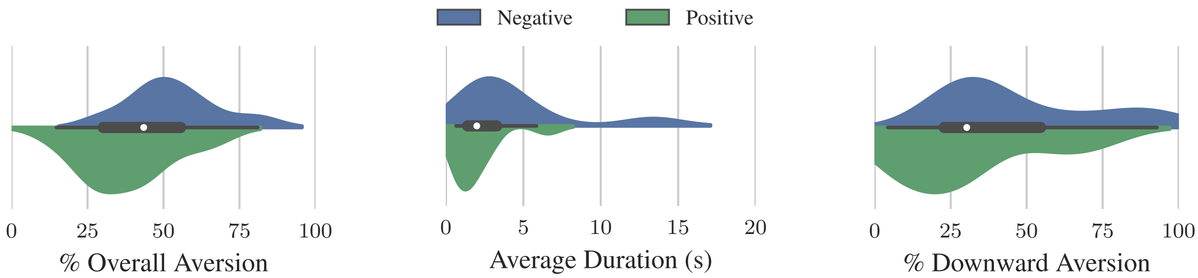
Individual Scale Item	Brief Description of Behavior
Positive Scale	
Delusions	Beliefs which are unfounded, unrealistic, and idiosyncratic.
Conceptual Disorganization	Disorganized process of thinking characterized by disruption of goal-directed sequencing, e.g., circumstantiality, tangentiality, loose associations, non-sequiturs, gross illogicality, or thought block.
Hallucinatory Behavior	Verbal report or behavior indicating perceptions which are not generated by external stimuli. These may occur in the auditory, visual, olfactory, or somatic realms.
Excitement	Hyperactivity as reflected in accelerated motor behavior, heightened responsivitiy to stimuli, hypervigilance, or excessive mood lability.
Grandiosity	Exaggerated self-opinion and unrealistic convictions of superiority, including delusions of extraordinary abilities, wealth, knowledge, fame, power, and moral righteousness.
Suspiciousness / Persecution	Unrealistic or exaggerated ideas of persecution, as reflected in guardedness, a distrustful attitude, suspicious hypervigilance, or frank delusions that others mean one harm.
Hostility	Verbal and nonverbal expressions of anger and resentment, including sarcasm, passive-aggressive behavior, verbal abuse, and assaultiveness.
Negative Scale	
Blunted Affect	Diminished emotional responsiveness as characterized by a reduction in facial expression, modulation of feelings, and communicative gestures.
Emotional Withdrawal	Lack of interest in, involvement with, and affective commitment to life's events.
Poor Rapport	Lack of interpersonal empathy, openness in conversation, and sense of closeness, interest, or involvement with the interviewer. This is evidenced by interpersonal distancing and reduced verbal and nonverbal communication.
Passive / Apathetic Social Withdrawal	Diminished interest and initiative in social interactions due to passivity, apathy, anergy, or avolition. This leads to reduced interpersonal involvement and neglect of activities of daily living
Difficulty in Abstract Thinking	Impairment in the use of the abstract-symbolic mode of thinking, as evidenced by difficulty in classification, forming generalizations, and proceeding beyond concrete or egocentric thinking in problem-solving tasks.
Lack of Spontaneity and Flow of Conversation	Reduction in the normal flow of communication associated with apathy, avolition, defensiveness, or cognitive deficit. This is manifested by diminished fluidity and productivity of the verbal-interactional process.
Stereotyped Thinking	Decreased fluidity, spontaneity, and flexibility of thinking, as evidenced in rigid, repetitious, or barren thought content.

H1.1. *Individuals expressing positive subtype schizophrenia avert their gaze less than those expressing negative subtype schizophrenia.* The first hypothesis examines the raw percentage of the interview in which participants are not averting their gaze from the interviewing clinician. This hypothesis is grounded in the understanding that individuals scoring highly on the positive symptom scale express such symptoms as hostility and suspiciousness, which may result in less gaze aversion. There was a statistically significant difference between groups at the 95% confidence level as determined by a one-way ANOVA [$F(1, 19) = 5.049$, $p = 0.037$] (see Figure 3a). A post-hoc comparison indicated that the average percentage of aversion over the session for individuals expressing positive subtype ($M = 38.34\%$, $SD = 14.86\%$) was significantly smaller than the average percentage for individuals expressing negative subtype ($M = 52.94\%$, $SD = 14.57\%$). This result suggests that individuals expressing positive subtype schizophrenia avert their gaze less often, in general, than individuals expressing negative subtype schizophrenia.

H1.2. *Individuals expressing negative subtype schizophrenia avert their gaze for longer periods of time than individuals expressing positive subtype schizophrenia.* The second hypothesis examines the average temporal length of gaze aversions when they do occur. This hypothesis is based on the defining features of negative symptoms such as poor rapport and social withdrawal, which may suggest more consistent aversion behavior. There was a statistically significant difference between groups at the 95% confidence level as determined by a Kruskal-Wallis H-test[2] [$H(1) = 5.838$, $p = 0.016$] (see Figure 3b). A post-hoc comparison indicated that the average aversion duration for individuals expressing positive subtype schizophrenia ($M = 1.93$s, $SD = 1.63$s) was significantly smaller than for individuals expressing negative subtype ($M = 4.23$s, $SD = 3.69$s). This result suggests that when individuals expressing negative subtype schizophrenia avert their gaze, they are likely to do so for a longer period of time than individuals expressing positive subtype.

H1.3. *Individuals expressing positive subtype schizophrenia cover larger area during aversions than individuals expressing negative subtype schizophrenia.* The third hypothesis examines the average distance covered during gaze aversions. This hypothesis is based on the suggestion that positive subtype schizophrenia involves a degree of hyperactivity and excitement, lending to fewer gaze fixations. To operationalize this definition,

2. Both distributions failed a Shapiro-Wilk test for normality: positive subtype [$W(12) = 0.705$, $p = 0.001$] and negative subtype [$W(9) = 0.705$, $p = 0.002$].



(a) **H1.1.** Percentage of the interview in which gaze was averted. [$F(1, 19) = 5.049$, $p = 0.037$]

(b) **H1.2.** Average duration of an aversion (in seconds). [$H(1) = 5.838$, $p = 0.016$]

(c) **H1.5.** Percentage of aversions that were (non-exclusively) downward. [$H(1) = 2.909$, $p = 0.088$]

Figure 3. An illustration of a selection of the distributions most significantly different between participants expressing positive- versus negative-subtype schizophrenic symptoms. As some of the distributions fail normality tests, we illustrate using the violin plot, an alternative to the traditional box plot that also accurately represents the distribution of the data using smoothed density plots. The center line represents the median and interquartile range of the dataset, much like a traditional box plot.

for each aversion event, each two-dimensional directional annotation is treated as a point in $\{-1, 0, +1\}^2$-space, and the Euclidean distance $\|\boldsymbol{x_i} - \boldsymbol{x_{i+1}}\|$ is calculated between every pair of consecutive points $\boldsymbol{x_i}$ and $\boldsymbol{x_{i+1}}$ along the aversion path. The sum of these distances results in a measure of the distance covered over the course of the aversion. There was *not* a statistically significant difference between groups at the 95% confidence level as determined by a Kruskal-Wallis H-test[3] [$H(1) = 1.823$, $p = 0.177$].

H1.4. *Individuals expressing positive subtype schizophrenia are more likely to avert their gaze laterally than individuals expressing negative subtype schizophrenia.* The fourth hypothesis examines the proportion of aversions that are (non-exclusively) lateral. Vertical aversions are often associated with anxiety, which is more canonically associated with the social withdrawal and poor rapport of negative subtype schizophrenia. There was *not* a statistically significant difference between groups at the 95% confidence level as determined by a Kruskal-Wallis H-test[4] [$H(1) = 1.548$, $p = 0.213$].

H1.5. *Individuals expressing negative subtype schizophrenia are more likely to avert their gaze downward than individuals expressing positive subtype schizophrenia.* The final hypothesis examines the proportion of aversions that are (non-exclusively) downward. Downward aversions have previously been suggested to be significantly indicative of persons diagnosed with depression [8], which is often associated with many negative schizophrenic symptoms. There was *not* a statistically significant difference between groups at the 95% confidence level as determined by a Kruskal-Wallis H-test[5] [$H(1) = 2.909$, $p = 0.088$] (see Figure 3c).

3. Both distributions failed a Shapiro-Wilk test for normality: positive subtype [$W(12) = 0.855$, $p = 0.043$] and negative subtype [$W(9) = 0.822$, $p = 0.036$].

4. The positive subtype distribution failed a Shapiro-Wilk test for normality [$W(12) = 0.598$, $p = 0.000$].

5. The negative subtype distribution failed a Shapiro-Wilk test for normality [$W(9) = 0.814$, $p = 0.029$].

4.2. Aversion and Dialogue

The second set of hypotheses tested involves eye contact and gaze aversion as related to dialogue and question types (see Section 3.2 for details).

H2.1. *Introspective questions result in more gaze aversion than extrospective questions.* The first hypothesis examines the difference in gaze aversion during introspective and extrospective questions. Introspective questions involve evaluating intimate details about the self, which often induces discomfort or unease. There was a statistically significant difference within subjects as determined by an ANOVA with repeated measures [$F(1, 20) = 7.347$, $p = 0.013$]. A post-hoc comparison indicated that the average proportion of aversion during introspective questions ($M = 53.70\%$, $SD = 21.21\%$) was significantly more than during extrospective questions ($M = 49.89\%$, $SD = 17.78\%$). This result suggests that regardless of subtype, individuals expressing schizophrenia are more likely to avert their gaze during introspective questions than during extrospective questions.

H2.2. *Individuals expressing negative subtype schizophrenia avert their gaze more often during introspective questions than individuals expressing positive subtype schizophrenia.* The second hypothesis suggests that individuals expressing negative subtype schizophrenia would avert their gaze more frequently during introspective questions than their positive subtype counterparts. This was informed by the prominent negative scale item involving difficulty in abstract thinking, which may result in difficulty answering this type of interview question. There was a statistically significant difference between groups as determined by a one-way ANCOVA while controlling for overall aversion percentage [$F(1, 18) = 6.486$, $p = 0.020$]. A post-hoc comparison indicated that the average proportion of aversion during introspective questions for individuals expressing positive subtype schizophrenia ($M = 41.33\%$,

$SD = 13.66\%$) was significantly less than for individuals expressing negative subtype ($M = 61.81\%$, $SD = 16.12\%$). This result suggests that individuals expressing negative subtype schizophrenia are more likely to avert their gaze during introspective questions than individuals expressing positive subtype schizophrenia.

4.3. Aversion and Facial Expression

The final set of hypotheses examines the facial expressions conveyed during gaze aversions (see Section 3.3).

H3.1. *When averting gaze, individuals expressing positive subtype schizophrenia express more* AU2 OUTER BROW RAISER *than individuals expressing negative subtype schizophrenia.* The first hypothesis examines the average expression of AU2 OUTER BROW RAISER during gaze aversions. Brow raising is often associated with fear, surprise, and other spontaneous emotions [15], which may be more present in individuals expressing positive symptoms such as excitement and hyperactivity. There was a statistically significant difference between groups as determined by a one-way ANCOVA while controlling for average overall AU2 intensity [$F(1, 18) = 5.627$, $p = 0.029$]. A post-hoc comparison indicated that the average AU2 intensity expressed during aversion for individuals expressing positive subtype schizophrenia ($M = 0.847$, $SD = 0.316$) was significantly greater than for individuals expressing negative subtype ($M = 0.757$, $SD = 0.266$). This result suggests that individuals expressing positive subtype schizophrenia tend to express AU2 OUTER BROW RAISER when they avert their gaze more than individuals expressing negative subtype schizophrenia.

H3.2. *When averting their gaze, individuals expressing negative subtype schizophrenia express more* AU4 BROW LOWERER *than individuals expressing positive subtype schizophrenia.* The second hypothesis examines the average expression of AU4 BROW LOWERER during gaze aversions. Brow lowering is an expression canonically associated with negative emotions [15], which may be more present in persons expressing negative subtype schizophrenic symptoms. There was a statistically significant difference between groups as determined by a one-way ANCOVA while controlling for average overall AU4 intensity [$F(1, 18) = 5.643$, $p = 0.029$]. A post-hoc comparison indicated that the average AU4 intensity expressed during aversion for individuals expressing negative subtype schizophrenia ($M = 0.125$, $SD = 0.053$) was significantly greater than for individuals expressing positive subtype ($M = 0.057$, $SD = 0.047$). This result suggests that individuals expressing negative subtype schizophrenia tend to express AU4 BROW LOWERER when they avert their gaze more than individuals expressing positive subtype schizophrenia. Prior work on individuals expressing schizophrenia without regard to subtype has identified this expression as generally indicative of schizophrenia [16], so the suggestion that this facial expression is expressed differently between subtypes is notable.

H3.3. *When averting their gaze, individuals expressing negative subtype schizophrenia express more* AU14 DIMPLER *than individuals expressing positive subtype schizophrenia.* The third hypothesis examines the average expression of AU14 DIMPLER during gaze aversions. AU14 DIMPLER is often associated with contempt, which may be more prevalent in individuals expressing negative subtype schizophrenia than those expressing positive subtype. There was *not* a statistically significant difference between groups as determined by a one-way ANCOVA while controlling for average overall AU14 intensity [$F(1, 18) = 3.922$, $p = 0.063$].

H3.4. *When averting their gaze, individuals expressing negative subtype schizophrenia express more* AU20 LIP STRETCHER *than individuals expressing positive subtype schizophrenia.* The final hypothesis examines the average expression of AU20 LIP STRETCHER during gaze aversions. AU20 is often likened to a 'grimace' of the face, which occurs relatively infrequently in social interaction, but prior work has suggested a particular aversion to 'negative affect' facial expressions in schizophrenia [17]. There was *not* a statistically significant difference between groups as determined by a one-way ANCOVA while controlling for average overall AU20 intensity [$F(1, 18) = 0.165$, $p = 0.689$].

5. Predictive Models

In order to approach prediction of schizophrenic symptom severity from both a typological and a dimensional assessment perspective, two sets of computational models were built. The first analysis, described in Section 5.2, approaches the typological perspective, with the target of predicting an individual's schizophrenic subtype based on gaze aversion behavior descriptors. The second analysis, described in Section 5.3, addresses the dimensional perspective, using these gaze aversion behavior descriptors to predict quantitative scores on the PANSS inventory [5].

5.1. Computational Descriptors

Based on the results of the statistical analyses conducted previously, a series of thirteen behavior descriptors were extracted from each interview session. This set of descriptors was provided as a set of features to both the typological and the dimensional predictive analyses.

Gaze aversion percentage. Over the course of the entire interview session, the percentage of time in which the participant averted their gaze from the interviewing clinician.

Gaze aversion percentage (introspective). Over the course of all introspective question segments (see Section 3.2), the percentage of time in which the participant averted their gaze from the interviewing clinician.

Aversion duration. Across the set of all aversion events, the average temporal duration of a gaze aversion.

Aversion distance. Across the set of all aversion events, the average distance covered in an aversion (see Section 4.1, H1.3. for operational definition). This allows for the distinction between fixation and gaze-wandering.

Lateral/vertical aversion percentage. (2 features) Across the set of all aversion events, the percentage of events

TABLE 3. TYPOLOGICAL EXPERIMENTS. PERFORMANCE OF THE AUTOMATICALLY VALIDATED SVM CLASSIFICATION MODEL IN TERMS OF ACCURACY, KRIPPENDORFF'S α, AND F_1 SCORE, AS COMPARED TO A MAJORITY-CLASS PREDICTOR BASELINE MODEL.

Model	Accuracy	Krippendorff's α	F_1 Score
SVM	76.19%	0.5309	0.7597
Baseline	57.14%	-0.2424	0.3636

TABLE 4. DIMENSIONAL EXPERIMENTS. PERFORMANCE OF THE AUTOMATICALLY VALIDATED ϵ-SVR REGRESSION MODELS IN TERMS OF PEARSON'S r.

Model	Pearson's r	p
Positive Score	0.5853	0.005
Negative Score	0.4330	0.049
Composite Score	0.5714	0.006

in which the participant made a lateral/vertical aversion. A lateral/vertical aversion is an event in which the participant's gaze drifts (non-exclusively) laterally/vertically from direct gaze toward the interviewing clinician.

Directional aversion percentage. (4 features) Across the set of all aversion events, the percentage of events in which the participant made an aversion in one of the four cardinal directions: left, right, up, or down. A directional aversion is an event in which the participant's gaze drifts (non-exclusively) in that direction relative to direct gaze toward the interviewing clinician.

Average AU2 intensity during aversion. Across all aversion events, the average expressed intensity of AU2 OUTER BROW RAISER (see Figure 2a).

Average AU4 intensity during aversion. Across all aversion events, the average expressed intensity of AU4 BROW LOWERER (see Figure 2b).

Average AU14 intensity during aversion. Across all aversion events, the average expressed intensity of AU14 DIMPLER (see Figure 2c).

5.2. Typological Assessment

The typological assessment is framed as a classification problem in which the target class value is either positive or negative subtype (see Section 3). A set of support vector machine (SVM) classifiers [18] were trained for this task using leave-one-person-out cross-testing, following leave-one-person-out cross-validation for hyperparameter tuning and feature selection using logistic regression [19]. Models were validated upon Krippendorff's α. The model was allowed to take on either a linear kernel $K(\boldsymbol{x}, \boldsymbol{x'}) = \boldsymbol{x}^T \boldsymbol{x'}$ or a Gaussian radial basis function (RBF) kernel $K(\boldsymbol{x}, \boldsymbol{x'}) = \exp(-\gamma \|\boldsymbol{x} - \boldsymbol{x'}\|^2)$, for any two feature vectors $\boldsymbol{x}, \boldsymbol{x'} \in \mathbb{R}^9$. Hyperparameters validated include $C \in \{10^{-5}, 10^{-4}, \ldots, 10^4\}$ and, in the case of the Gaussian-RBF kernel, $\gamma \in \{0.00, 0.05, \ldots, 1.00\}$.

Performance of cross-testing in terms of accuracy, Krippendorff's α, and F_1 score is displayed in Table 3, alongside a baseline majority-class predictor. This classification model achieved a performance well above the majority-class baseline during cross-testing. Although the Krippendorff's α does not reach a 'reliable' level of agreement [12], the moderate level of performance achieved does suggest the existence of significant information regarding the identification of schizophrenic subtype in an individual's gaze aversion behaviors.

5.3. Dimensional Assessment

The second task of dimensional assessment is framed as a regression problem in which the target class value is either the individual's total Positive Scale score (values 7 to 49), the individual's total Negative Scale score (values 7 to 49), or the individual's composite score (values -42 to 42). A series of ϵ-support vector regressors (ϵ-SVRs) [20] were trained for this task using leave-one-person-out cross-testing, following leave-one-person-out cross-validation for hyperparameter tuning and feature selection using LASSO [21]. Models were optimized upon Pearson's r. The model was validated upon the same hyperparameters specified in Section 5.2; in addition, the range parameter ϵ was validated within $\epsilon \in \{10^{-5}, 10^{-4}, \ldots, 10^{-1}\}$.

Performance of the best-performing regression models in terms of Pearson's r is displayed in Table 4. All three models were able to achieve a reasonable level of correlation with true PANSS scores during cross-testing. All of these correlations were statistically significant at the 95% confidence level. Prediction of raw dimensional scores is a more complex task than prediction of coarse typological subtype, but the promising results achieved reinforce the proposition that gaze aversion behavior is a prominent social signal containing information highly relevant to the identification of schizophrenic symptom severity.

6. Behavior Analysis

The final stage of this analysis examines one of the predictive models in detail, identifying and interpreting the significance of the most influential features. For this final step, a LASSO linear model [21] was trained upon the entire dataset, optimizing performance on composite score prediction in terms of Pearson's r. The model was limited to a selection of five features that best predicted the PANSS composite score of the participants. The LASSO model achieved a Pearson's $r = 0.65$ on the training set (compare to model performance in Section 5.3; note that this is performance on the training set, as opposed to leave-one-person-out validation). We review the five features selected; the model is presented in Table 5.

Gaze aversion during introspective questions. The most influential feature selected is the percentage of introspective question segments in which the individual is averting their gaze from the clinician. The more the participant averts their gaze during introspective questions, the lower their composite score tends to be, and by extension, the more negative symptoms they tend to express. This result was mirrored in Section 4.2, where there existed a statistically significant difference in aversion during introspective questions between persons expressing positive subtype and negative subtype schizophrenic symptoms.

Average intensity of AU4 BROW LOWERER during gaze aversion. The next feature selected is the average intensity of AU4 BROW LOWERER (see Figure 2b) during aversion events. The more intense the average brow lowering during gaze aversion, the lower the participant's composite score tends to be, and the more negative symptoms they tend to express. This result was also mirrored in Section 4.3, where there existed a statistically significant difference in AU4 expression during aversion events between persons expressing positive and negative symptoms.

Proportion of lateral gaze aversion. The only positively-correlated feature selected is the proportion of gaze aversions that were (non-exclusively) lateral aversions. The more gaze aversions in which the participant's gaze moves laterally, the higher their composite score tends to be, and the more positive symptoms they tend to express. Interestingly, this descriptor was *not* discriminative on its own in the statistical analyses in Section 4.1. This may suggest that it holds more discriminative information when combined with these other features.

Proportion of downward gaze aversion. The next feature selected is the proportion of gaze aversions that were (non-exclusively) downward aversions. The more gaze aversions in which the person looks downward, the lower their composite score tends to be, and the more negative symptoms they tend to express. This descriptor was also not considered a discriminative feature in the statistical analyses in Section 4.1, although it was more significant than lateral aversion.

Average gaze aversion duration. The final feature included, with relatively little influence, is the average length of time of an aversion event. The longer periods of time a person averts their gaze, the lower their composite score tends to be, and the more negative symptoms they tend to express. Although this descriptor was significantly discriminative between individuals expressing positive and negative subtype symptoms in Section 4.1, it was not very influential in this model; this may suggest that, although this feature is still discriminative, the prior features explain the difference more accurately than gaze aversion duration.

TABLE 5. FEATURES SELECTED BY A LASSO LINEAR MODEL WHEN LIMITED TO FIVE FEATURES, PREDICTING THE PANSS COMPOSITE SCORE OF THE PARTICIPANT.

PANSS Composite Score =
$-8.374 \times$ Gaze aversion during introspective questions
$-4.760 \times$ Average intensity of AU4 during gaze aversion
$+1.972 \times$ Proportion of lateral gaze aversion
$-0.725 \times$ Proportion of downward gaze aversion
$-0.001 \times$ Average gaze aversion duration
Pearson's $r = 0.653$, $p = 0.002$

7. Conclusion

Most psychiatric disorders are diagnosed with the aid of significant clinical evaluation of an individual's nonverbal and communicative behavior patterns. The present analysis aims to develop classifier models that can accurately differentiate between subtypes of schizophrenic symptoms based the patterns of eye contact and gaze aversion expressed by an individual during a clinical interview. A strength of this work is the approach to these behaviors through an investigation of symptom severity rather than coarse-grained diagnoses; since many symptoms are shared across comorbid conditions, this work can inform systems developed toward more personalized symptom-based care.

Statistical comparisons suggest a few interesting differences in behavior between positive and negative symptoms of schizophrenia. In general, individuals expressing negative-subtype schizophrenic symptoms tend to avert gaze from the clinician more and for longer periods of time, and this difference is even more notable during introspective questions. When these individuals do avert their gaze, they tend to lower their brows (AU4 BROW LOWERER) more than individuals expressing positive symptoms.

We have reported a predictive model able to distinguish between positive and negative subtype expressing individuals with reliable performance based on gaze aversion behaviors during a clinical interview. In addition, predictive models are able to reasonably predict PANSS numeric scores on the Positive Scale and the Negative Scale, as well as the composite difference score. We identify the most influential behavior descriptors and potential interactions between them; most notably, the direction of gaze aversion becomes a discriminative feature when taken in concert with other descriptors. By approaching computational identification of schizophrenic symptom intensity from both a typological and dimensional perspective, this line of work constitutes a promising step in the development of technologies to aid clinicians in diagnosis of psychiatric illnesses.

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