EarlyScreen: Multi-scale Instance Fusion for Predicting Neural Activation and Psychopathology in Preschool Children

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Emotion Regulation in Early Childhood

Integral part of early childhood development.

Poor emotion regulation predicts range of psychological disorders (e.g., ADHD, mood and anxiety disorders).

Hard to distinguish from normative misbehavior (e.g., temper tantrums).

Current Diagnostic Practices

Clinical questionnaires (e.g., CBCL) filled by parents

- Modest diagnostic accuracy (sensitivity 0.66, specificity 0.83).
- Indirect/biased measure.

Comprehensive interactions or observations of the child

- Time-consuming – ADOS requires 2-3 hour-long sessions.
- Long waitlists and cost burdens.

Do not consider neurological underpinnings of symptoms

- Association between clinical irritability and low activation of lateral prefrontal cortex.
- No access to neuroimaging in the field.

Image source: Grabell et al. *Evidence of Non-Linear Associations between Frustration-Related Prefrontal Cortex Activation and the Normal:Abnormal Spectrum of Irritability in Young Children* (2018).

EarlyScreen

Screening Tool for Emotion Dysregulation in Preschool Children

Direct Measurement of Child Behavior

- Record behavioral correlates including facial expressions and movement.
- Less burdensome and fewer obstacles for parents.

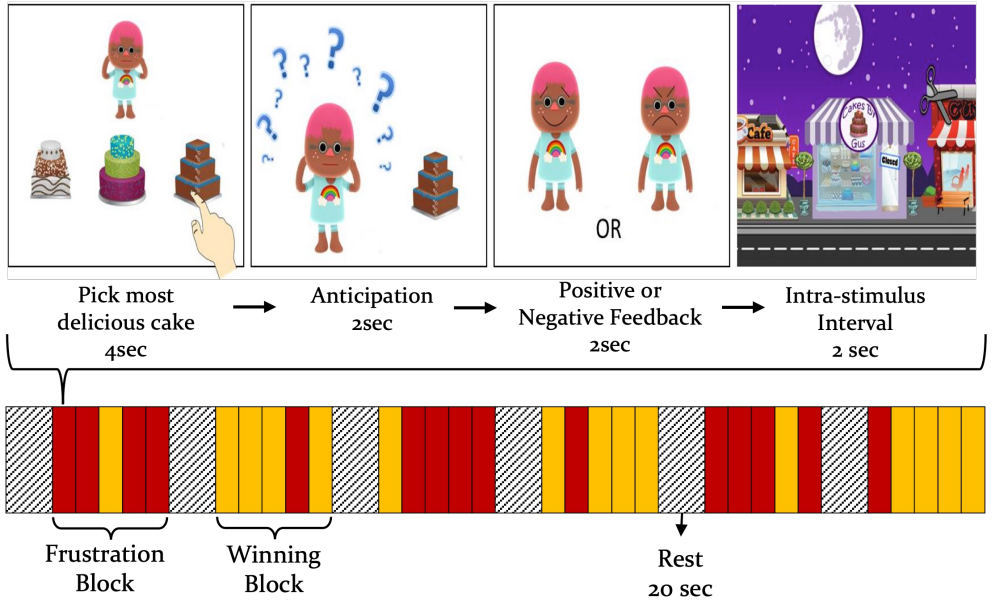
Rapid and Accessible

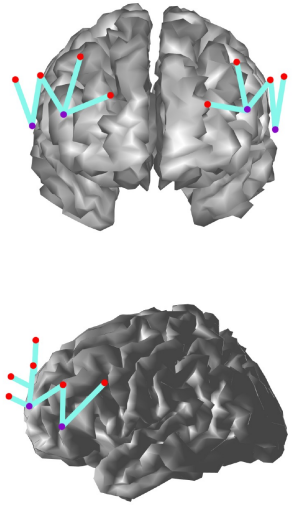
- Less than 10 minutes of behavioral data.
- Future home deployment on a tablet with a camera.

Neural Information in the Wild

- Predict lPFC activation during frustration.
- Additional modality for clinical diagnosis.

EarlyScreen Study





- 94 participants aged 3.5 to 5 years completed a clinically-validated frustration inducing task.
- Parents completed diagnostic questionnaires about child's behavior.

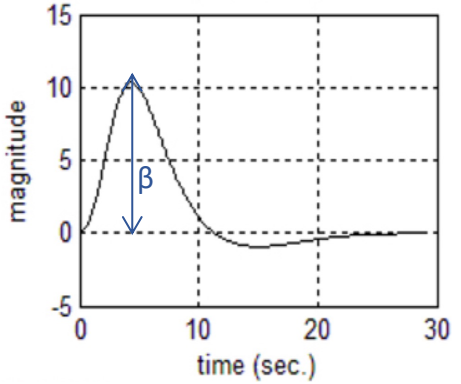
Simultaneous neural and behavioral recording:

- Facial expressions, eye and head movement using video cameras.
- Lateral PFC activation using functional Near-Infrared Spectroscopy (fNIRS).

Indicators of Early Psychopathology

Low lateral prefrontal cortex activation during frustration

- Measure change in oxyhemoglobin (ΔHbO_2) during frustration blocks
- Lower β indicates poor emotion regulation
  => higher risk of psychopathology



Clinical symptoms based on parental questionnaires

- Four subscales that measure most prevalent childhood problems
- Above clinical threshold on at least one scale
  => clinical categorization

Image source: Kamran et al. *Optimal hemodynamic response model for functional near-infrared spectroscopy* (2015).

Behavioral Correlates

Facial Expressions

- Presence and Intensity of 18 discrete Action Units
- Positive and Negative expression categories

Eye Gaze

- Change in gaze angle

Head Movement

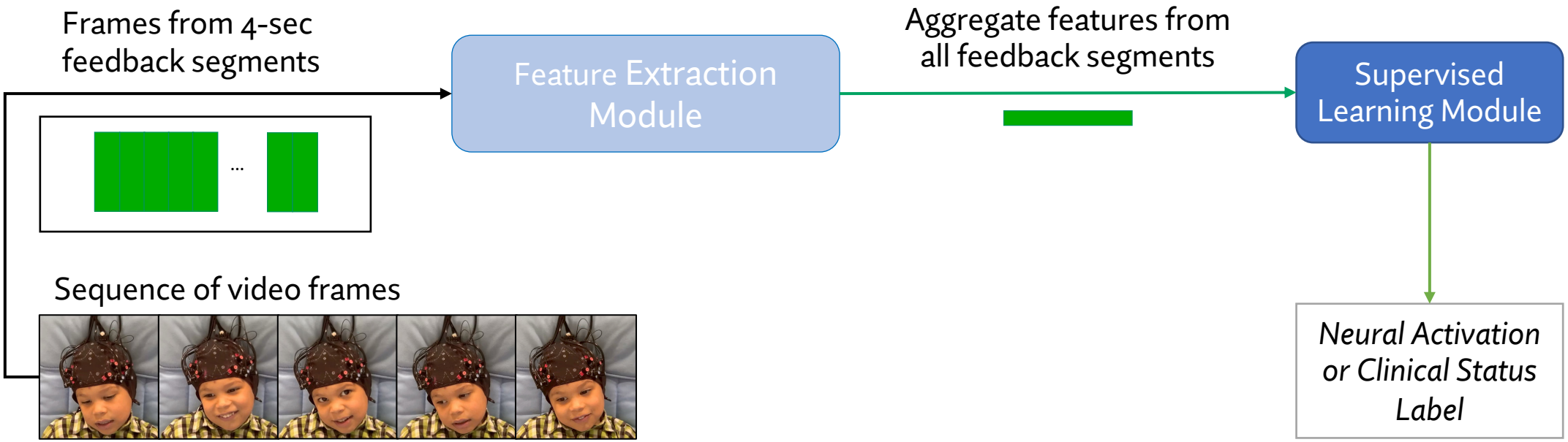
- Change in head position relative to camera

Grouped into 6 Feature Sets

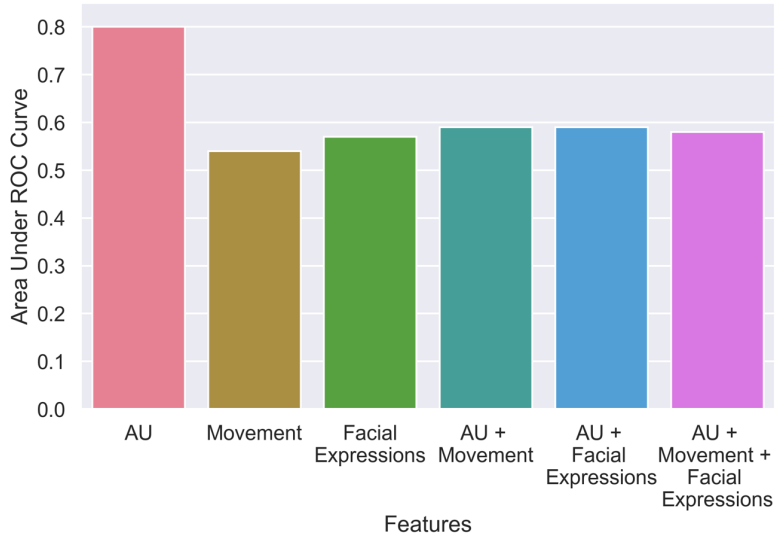
▪ Action Units (AUs) ▪ Facial expressions	▪ Movement (eye and head) ▪ AU + movement	▪ AU + Facial expressions ▪ AU + Movement + Facial Expressions

Classification Baselines and Features

- **Evaluate feasibility:** can behavioral features predict neural activation and clinical risk?
- **Feature set and model selection:** 5-fold cross-validation area under ROC curve



Classification Baselines and Features

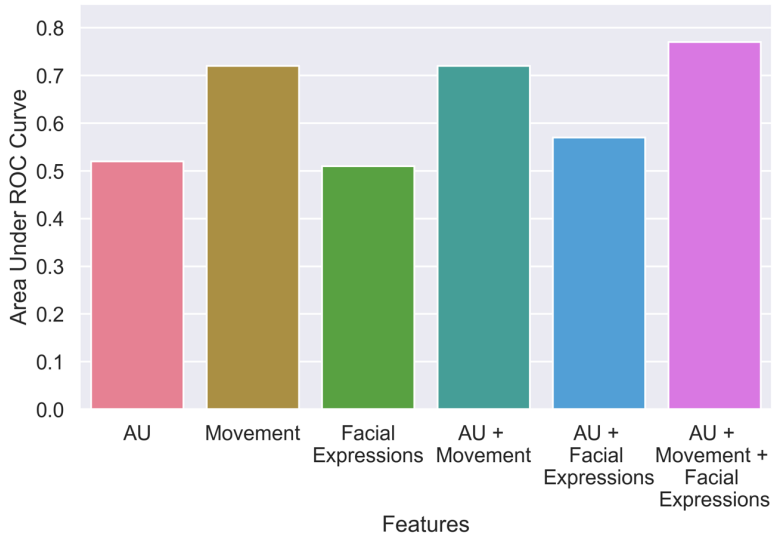


Neural Activation

Baseline performance: 0.80 AUROC

Best features: AU features

Best model: Random Forest



Clinical Status

Baseline performance: 0.77 AUROC

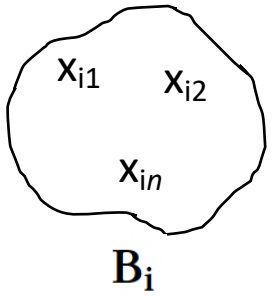
Best features: AU + Movement + Facial Expressions

Best model: AdaBoost

Improving Predictions

- **Limitation:** Single label per individual => small number of samples.
- **Opportunity:** Multiple trials per individual => opportunity to learn from fine- and coarse-grained data.

Multiple Instance Learning



label Y_i

Standard MIL Assumption: $$Y_i = \begin{cases} +1 & \text{if } \exists y_{ij} : y_{ij} = +1 \\ -1 & \text{if } \forall y_{ij} : y_{ij} = -1 \end{cases}$$

EarlyScreen Task Setting:

- No instance-level labels y_{ij} .
- Need to learn bag-level labels independently.

Proposal

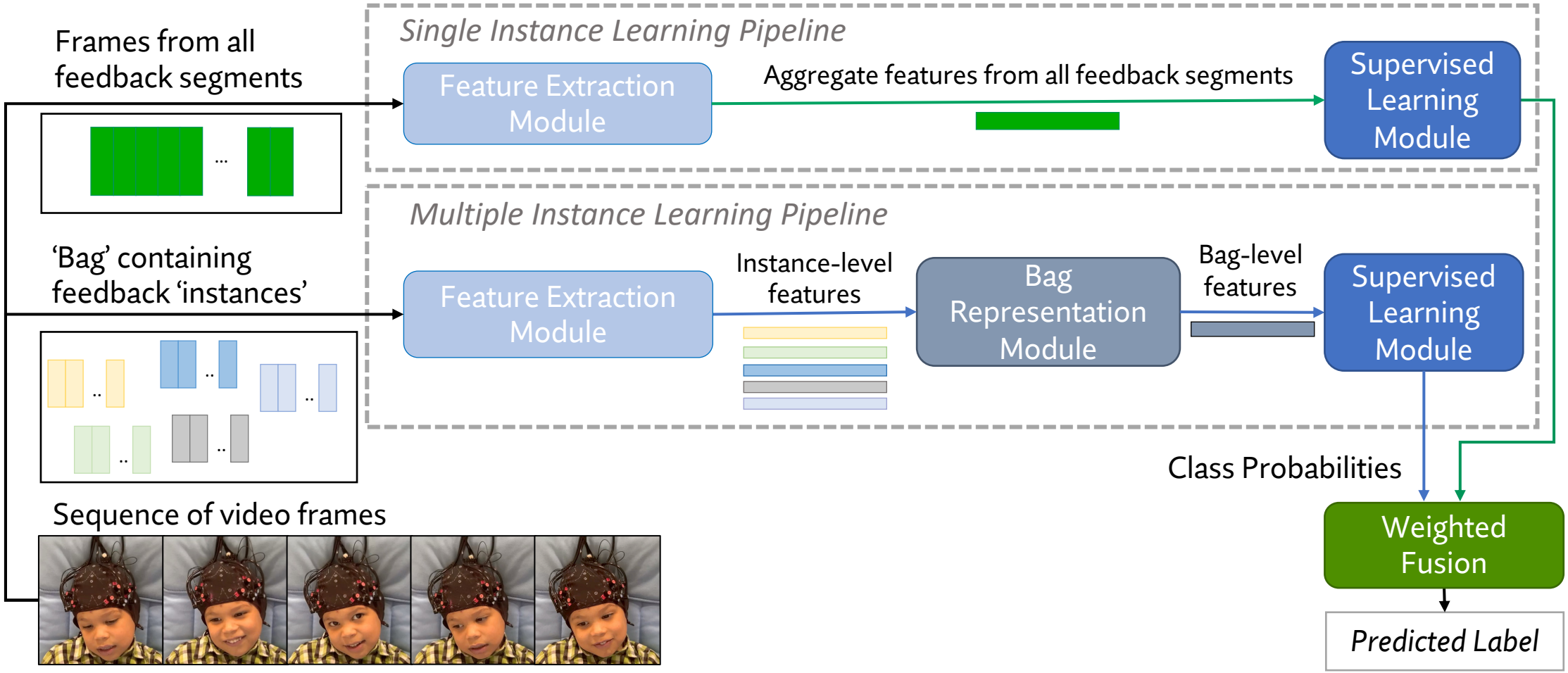
- MIL pipeline with a bag representation module, learning transformation from instance-level feature space to bag-level space:

$$f: \mathbf{B_i} \rightarrow \mathbf{B_i^{\phi}}$$

- Use $\mathbf{B_i^{\phi}}$ as input to supervised model to extract Y_i.

- Combine MIL pipeline with the baseline “single instance learning” pipeline.

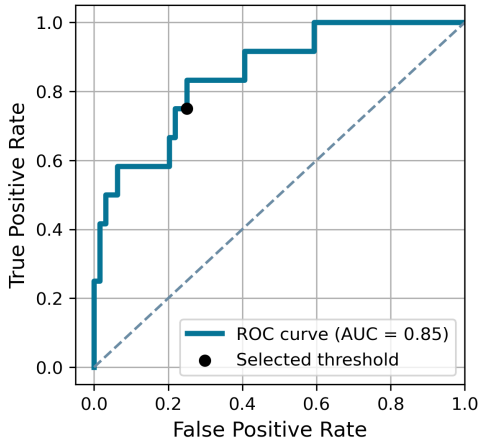
Multi-scale Instance Fusion Framework

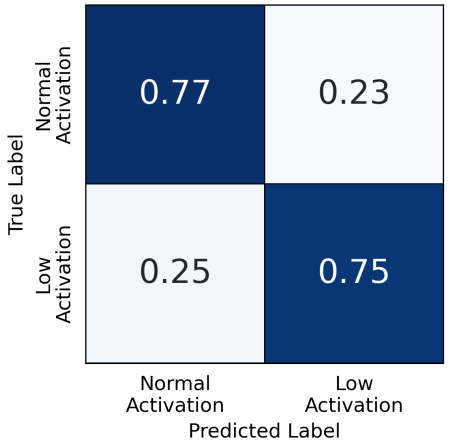


Classification Performance of MIF Models

lPFC Activation: AUROC of 0.85
(compared to 0.80 for SIL model)

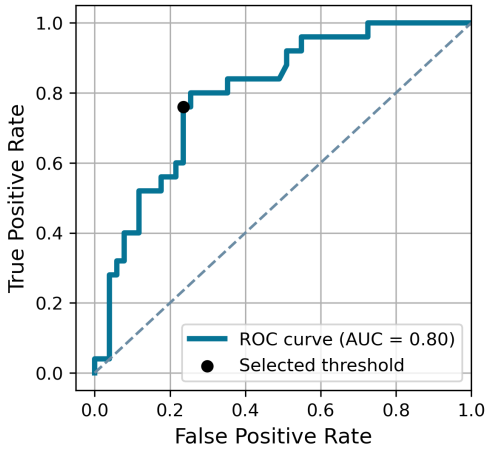
Using AU features and
polynomial minimax kernel
for bag representation.

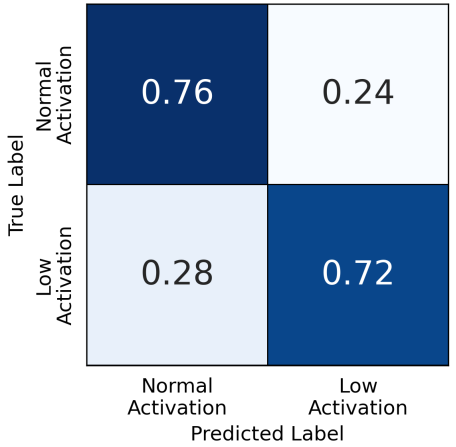




Clinical Status: AUROC of 0.80
(compared to 0.77 for SIL model)

Using AU + Movement + Facial
Expressions and MInD mapping
for bag representation.



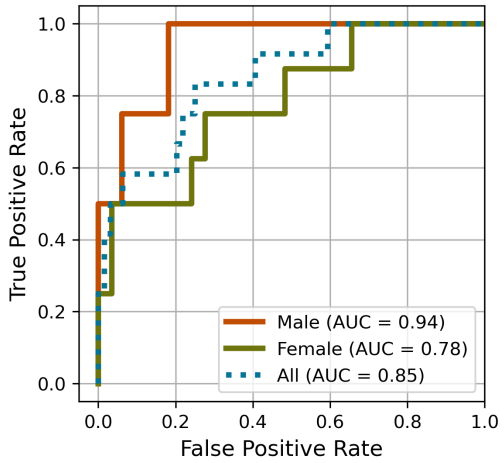


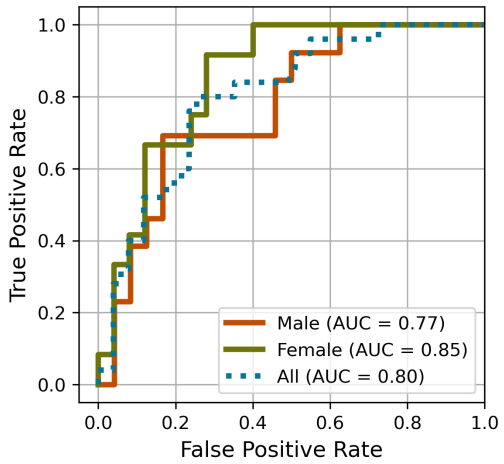
Demographic Fairness

IPFC Activation

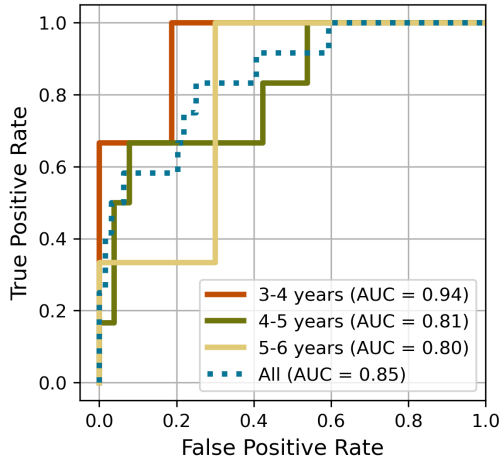
Clinical Status

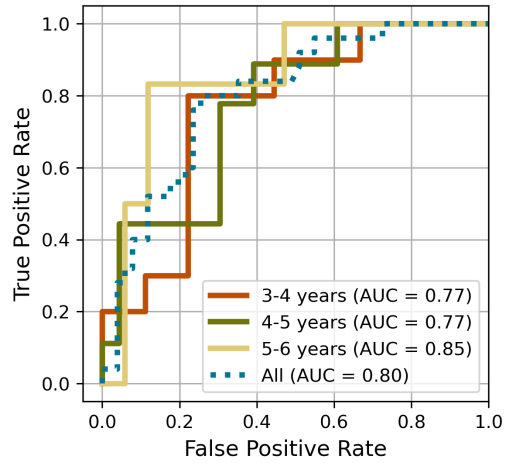
Sex



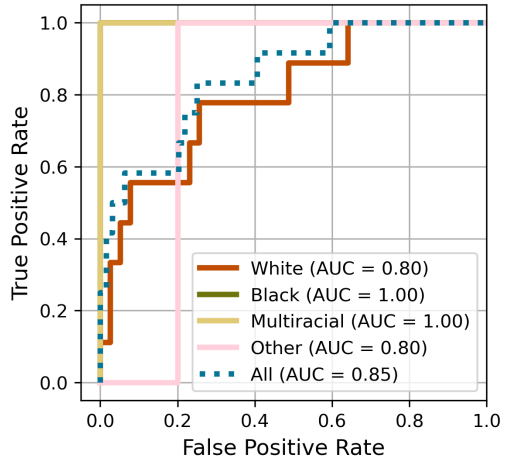


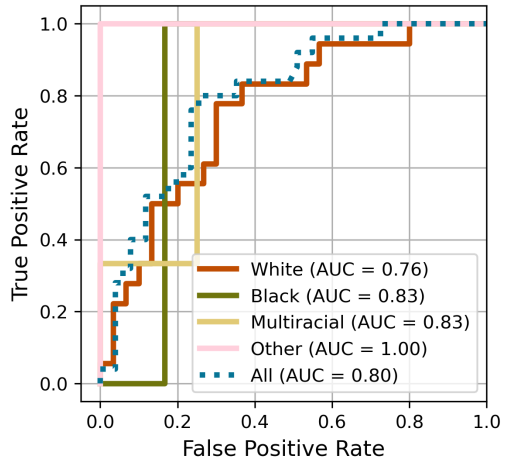
Age





Race





Practitioners' Perspective on EarlyScreen

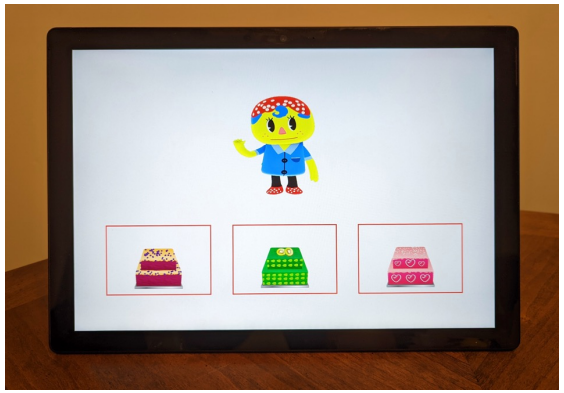
Asked 60 mental health practitioners about

- current diagnostic practices.
- utility of EarlyScreen and concerns regarding deployment.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
As a field, we need to improve the accuracy, efficiency, and convenience of how we diagnose early childhood mental illness.	1	0	1	11	41
A patient's biological data could someday improve the accuracy of their diagnosis.	0	2	11	31	9
Inexpensive and widely available neuroimaging data could someday improve diagnostic accuracy.	3	5	15	19	11
Continuous behavioral data collected in home settings could someday improve diagnostic accuracy.	1	1	5	24	23
In the future, using home-based games such as EarlyScreen can help provide useful diagnostic information that can add to currently available methods.	0	2	5	30	12
The preliminary accuracy of EarlyScreen's models is encouraging for future tests and subsequent deployment as an additional diagnostic tool.	0	2	7	25	15
Apps such as EarlyScreen could be useful for collecting ecologically valid data in home settings.	0	1	4	31	13
I am concerned about the data privacy of such an application.	2	10	10	20	7
I am concerned about the ethical considerations behind such an application.	3	10	11	19	6

Next Steps

Testing on larger populations and in diverse conditions.



At-home deployment using a tablet-based game.

Integrating wearable sensor data for more accurate predictions.

Image source: Empatica (https://www.empatica.com/blog/considering-embrace2-for-your-child.html)

For more details, see our paper

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