Relationship between Eye Movement Characteristics and Electrodermal Activity Associated with Decreased Level of Arousal

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Given that a decline in arousal while driving increases the risk of traffic accidents, the development of highly accurate and continuous arousal-monitoring technologies is crucial. It is well known that skin conductance and eye movements are objective indicators of arousal. Skin conductance, which is indicative of psychogenic sweating from the sympathetic nervous system (Shiihara et al., 1999), is relatively easy to measure. However, their application in real-world settings is constrained by the need to wear sensors. Conversely, eye movements, which can be measured using in-vehicle cameras, are gaining attention as biological indicators of arousal status that do not require sensors. In a previous study, researchers analyzed the characteristics of fixation eye movements just before a Slow Eye Movement (SEM), using the SEM's onset time as a reference. The findings revealed that the dynamic features of microsaccades and drift components of fixation eye movements serve as effective objective indicators of arousal levels (Mineta et al., 2026). However, the SEM, which has been confirmed as a reproducible indicator of reduced arousal, is defined in relation to electrooculogram (EOG) data. It remains to be determined whether it shares the same properties as the SEM estimated using the eye-tracking device reported by Mineta et al.

In this study, we aimed to clarify whether the SEM estimated from fixation eye movements could serve as an objective indicator of arousal. We simultaneously measured skin conductance and fixation eye movements to verify whether synchronized fluctuations occurred in both measures as arousal decreased. We applied the SEM detection method using the short-time Fourier transform proposed by Mineta et al. to the acquired fixation eye movement data (Fig.1). Additionally, for the skin conductance data, we applied cvxEDA, a signal decomposition method based on the convex optimization algorithm proposed by Greco et al. (2016), to extract the Skin Conductance Level (SCL) (Fig.2). To quantify the rate of increase or decrease in SCL, we performed a moving linear regression analysis on the SCL extracted by cvxEDA, using a window width of 30 s and a shift width of 5 s to assess the trend of the regression coefficients (Fig.3). To analyze the time-series data of the regression coefficients, we employed a 100 s moving window with a 5 s overlap and conducted a one-sample t-test (one-tailed) for each interval to identify those where the mean of the regression coefficients was significantly negative (Fig.4). The analysis confirmed that SEM occurred in synchronization with the periods when the SCL slope was negative for all six experimental participants. Furthermore, for the four participants with sufficient recording durations, SEM occurred near intervals where the SCL regression coefficient was significantly negative.

These findings reveal that SEM, as estimated from fixation eye movements, occurs in synchronization with intervals of decreased SCL, which indicates reduced arousal, thus demonstrating that it can serve as a robust, non-contact objective indicator of arousal for future in-vehicle monitoring systems.

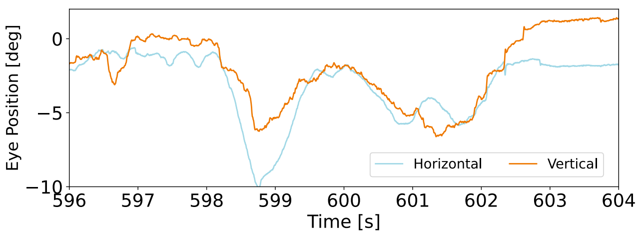

Fig.1 An example of a detected SEM

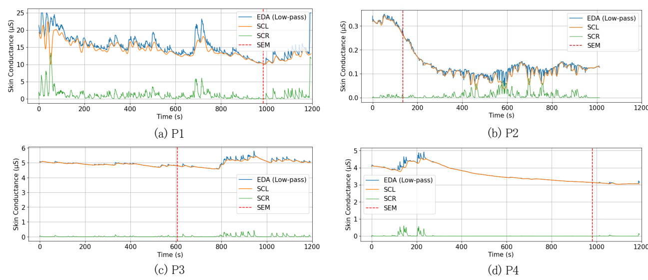

Fig.2 Relationship between SCL and detected SEM onset times for participants with sufficient recording durations

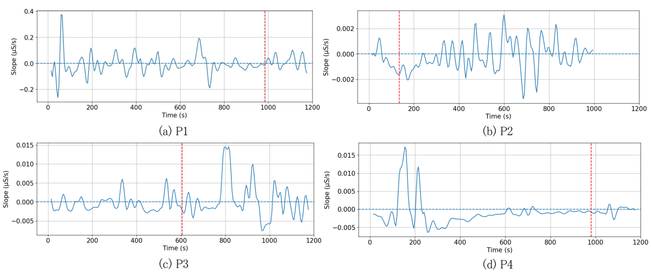

Fig.3 Time course of regression slope and SEM onset times for participants with sufficient recording duration

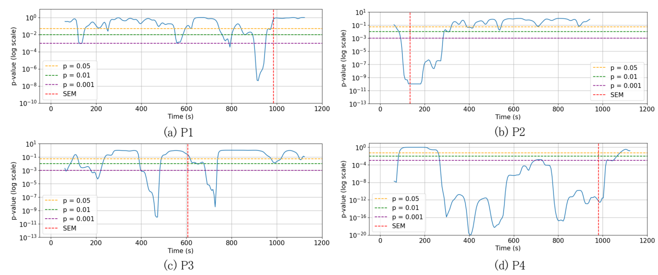

Fig.4 Time course of p-values for regression slopes and SEM onset times for participants with sufficient recording duration

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