SweatSponse: Closing the Loop on Notification Delivery Using Skin Conductance Responses

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ABSTRACT
Today's smartphone notification systems are incapable of determining whether a notification has been successfully perceived without explicit interaction from the user. If the system incorrectly assumes that a notification has not been perceived, it may repeat it unnecessary, disrupting the user, e.g., phone ringing. Conversely, if it incorrectly assumes that a notification was perceived, and therefore fails to repeat it, e.g., text message notification, the notification will be missed altogether. We introduce SweatSponse, a feedback loop using skin conductance responses (SCR) to infer the perception of smartphone notifications just after they are presented. Early results from a laboratory study suggest that notifications induce SCR and that they could be used to better predict perception of smartphone notifications in real-time.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Electrodermal activity, notifications, biosignal interactions

INTRODUCTION
Although intelligent devices are increasingly embedded into our daily lives, their interaction through notifications are in most cases operating using an open loop framework. This leads to two inefficient and potentially disruptive communication approaches. The first, usually used in synchronous communication contexts, e.g., phone calls, repeats an alert until it is explicitly acknowledged by being addressed or silenced. The second, most often employed for asynchronous interactions, e.g., text messaging, delivers a single alert and never reminds its user of the event.

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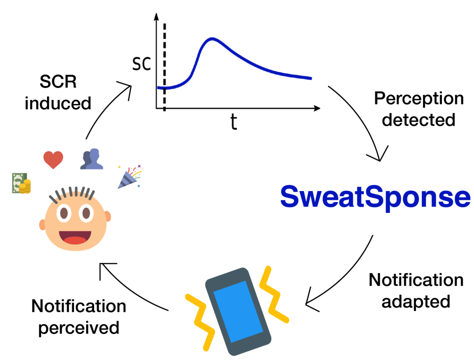

(a)

Figure 1: Proposed feedback loop. A notification is perceived by a user. The user anticipates the potential rewarding social interaction, which induces an SCR. SweatSponse captures the SCR using a wearable sensor, predicts whether it was perceived and feeds the information back to the notification system.

While prior work attempted to predict whether a stimulus or notification will be perceived based on its properties, e.g., intensity, duration, or frequency *before its presentation* [1, 3], there currently exists no method that can confirm *post-presentation* whether a notification was perceived without requiring the user to interact with their device. This perception feedback channel could allow a notification system to adapt its communication behavior approach by silencing, repeating, or otherwise modifying the sensory characteristics of a notification based on the user's perception (see Figure 1). In addition to increasing communication efficiency, we argue that the ability to confirm perception of stimuli without explicit interaction between users and their devices enables unique UI/UX opportunities and large-scale automated data collection procedures.

To this end, we introduce SweatSponse, a novel feedback loop relying on skin conductance responses (SCR) that allows systems to infer a user's perception of a vibrotactile or auditory notification, following its presentation, without explicit user intervention. The proposed method is based

Coefficients	Estimate	Std. Error	z value	p-value
Intercept	-0.37299	0.06910	-5.398	6.75e-08
PhasicMax	0.31177	0.07183	4.341	1.42e-05

Null deviance 1202.9 on 890 degrees of freedom.
Residual deviance 1182.7 on 889 degrees of freedom

Table 1: Logistic Regression analysis.

on the tight temporal coupling between delivery of a known stimulus and an observed SCR (1-4 s post-stimulus [5]), and long-term electrodermal activity recordings offered by recent wearable physiological sensor technologies such as Empatica's E4 and Thought Technology's TPS. It is hypothesized that smartphone notifications elicit SCR since they are known to cause the arousing anticipation of a potentially rewarding social interaction [6]. This work presents early findings from a laboratory study investigating the feasibility of using SCRs to infer perception of notifications.

USER STUDY

A user study was run to test the hypothesis that SCRs could be used to infer perception of smartphone notifications.

The study employed a Thought Technology TPS physiological sensor, attached to the participant's non-dominant hand. A notification logging application, installed on the participant's Android smartphone, was used to collect interaction data. Subjests were instructed to use the buttons on a smartwatch to report when they perceived notifications during two tasks: (1) watching a documentary and (2) completing a set of mazes. In addition to naturally occurring notifications, an artificial notification-inducing message was sent to the participants every 120 ± 20 seconds, to ensure collection of a sufficient number of data points.

Continuous decomposition analysis (CDA) was used to extract the phasic activity from the raw skin conductance signal [2]. The maximum of the phasic activity (PhasicMax) was extracted within a response window beginning one second after the notification was presented and extending for six additional seconds [5]. PhasicMax was z-scored for each participant to minimize the influence of inter-subject variability [2, 4].

RESULTS

A total of 17 subjects (19 to 29 years old, $\bar{x} = 24$) participated and received CAD$30 as compensation for two hours of their time.

A logistic regression model was trained and evaluated using leave one subject out (LOSO) cross-validation [1, 3]. PhasicMax was shown to statistically significantly contribute to the model's predictions as revealed by Wald's test (see Table 1). The model's coefficients reveal that an increase of one standard deviation in PhasicMax following the presentation of a notification increases the probability that the stimulus was perceived by $\exp(0.31177) = 1.366$. This supports our hypothesis that indeed, SCRs could be employed to infer whether a notification was perceived after its presentation.

A second test on the residual deviance is used to evaluate how well the proposed model fits the data [3]. Considering

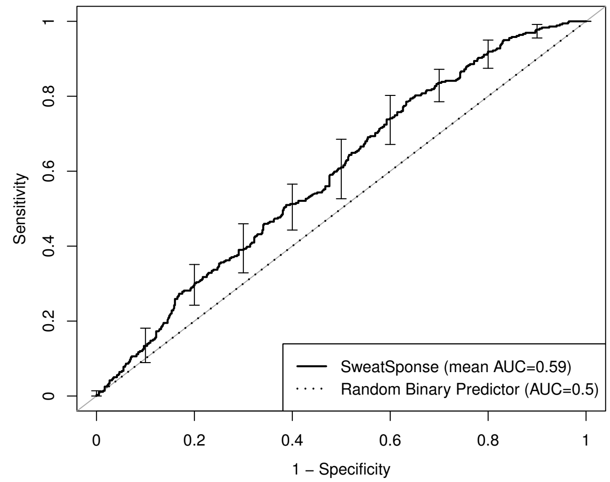

Figure 2: ROC curves generated from the proposed model compared against random predictions

that the probability that a χ^2 with 889 degrees of freedom would be greater than 1183 is $< .00001\%$ ($p < .05$), we *must reject* the null hypothesis that our logistic regression model provides an adequate fit of the data. Even though this test reveals sub-optimal model fitness, it does not invalidate the significant contribution of PhasicMax as an explanatory variable. It suggests, instead, that there exist other factors that were not accounted for in the current model that could explain the variance in the data.

To investigate whether our model can provide a meaningful advantage in a notification scenario, the model's receiver operating characteristic (ROC) curves was generated using the held-out subject's data from each LOSO split (see Figure 2). SweatSponse's AUC was found to be statistically significantly superior to random predictions as revealed by pROC's "Bootstrap" method ($AUC_{Sw} = .59$, D=5.5218, n.boot=2000, boot.stratified=1, $p < .0001$). The ROC curve and analysis of the model's coefficients suggest that smartphone notification perception can produce measurable eSCR which could be used by a system to provide perception feedback without explicit user intervention.

CONCLUSION

Promising results from this laboratory study suggest that SCR could be used to infer perception of smartphone notifications. However, much work still has to be done to validate the proposed system in the wild with naturally occurring notifications, and to explore the addition of other features that could enhance performance. Careful development of applications employing this method will have to be achieved, to ensure that the adaptive systems' behaviors offer repeatable and coherent user experiences.

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