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TITLE: Optimizing Energy Feedback Messages Using fNIRS

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1. Introduction

Energy feedback devices and their messaging capabilities can lower your monthly energy bills and help consumers save some extra money. Energy feedback messaging is an emerging socio-technical innovation that can help consumers save 5–20% on their monthly energy bills. These messages that stem from energy feedback devices can help consumers improve their homes energy efficiency. However, the effectiveness of energy feedback messages are lacking because there is no definite structure for delivering energy feedback. There is an opportunity to optimize the impact message design has on the delivery energy feedback messages, which builds upon prior literature on energy feedback messages (Barreto et al. 2013; Delmas et al. 2013; Hargreaves et al. 2013; Ehrhardt-Martinez et al. 2010). The motivation of this research study is to improve consumers energy consumption by personalizing energy feedback messages that highlight concepts people care about (e.g. comfortability, loss of income, preserving the environment). To measure the cognitive respose to energy feedback messages, an fNIRS study was conducted with 30 participants to measure their cognitive response to viewing energy feedback messages. Cognitive response shows that people are thinking about the content that is being presented to them. Also, we introduce a novel multidisciplinary approach to improve the effectiveness of current energy feedback message design by investigating cognitive response.

The framework we develop for this research study will build upon prior studies on energy feedback messages and use concepts from civil engineering, psychology, and sociology. In this framework, we combine existing message design theories (e.g. choice architecture, message types, colour, text type and size), prior literature on each of these messages, and a fNIRS instrument to gain a more accurate representation of which messages trigger the most cognitive response. My framework will uniquely utilize ideas and concepts from multiple disciplines (e.g. engineering, sociology, psychology, public works) to solve complex problems. This framework can help energy feedback devices excel regarding energy and monetary savings. Ultimately, this framework can use energy feedback messages to improve consumers energy behaviours

and reduce their carbon footprint.

2. Methods

Through measuring cognitive response with an fNIRS cap, researchers were able to measure brain activity while participants analysed energy feedback messages. fNIRS is a neuroimaging instrument that quantifies neurocognition (the functionality of one or more brain regions) via changes in blood flow patterns in the brain. The instrument operates by emitting near-infrared light into the human cortex, and the refracted light is detected by the sensors on the cap shown in Figure 1.

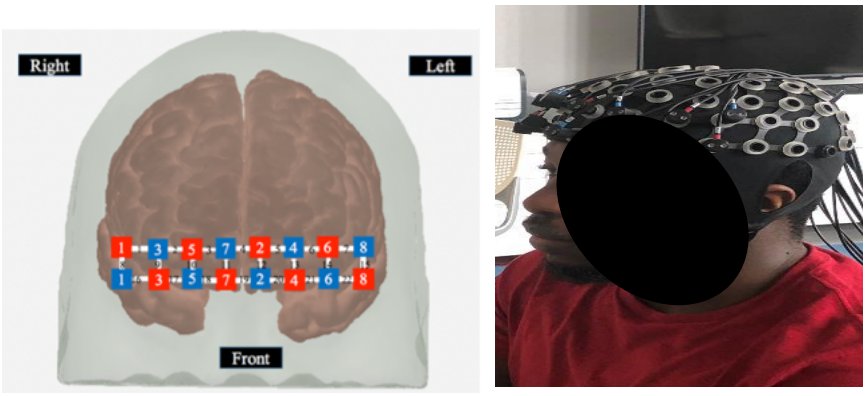


Figure 1. fNIRS Sensor-Covered Cap

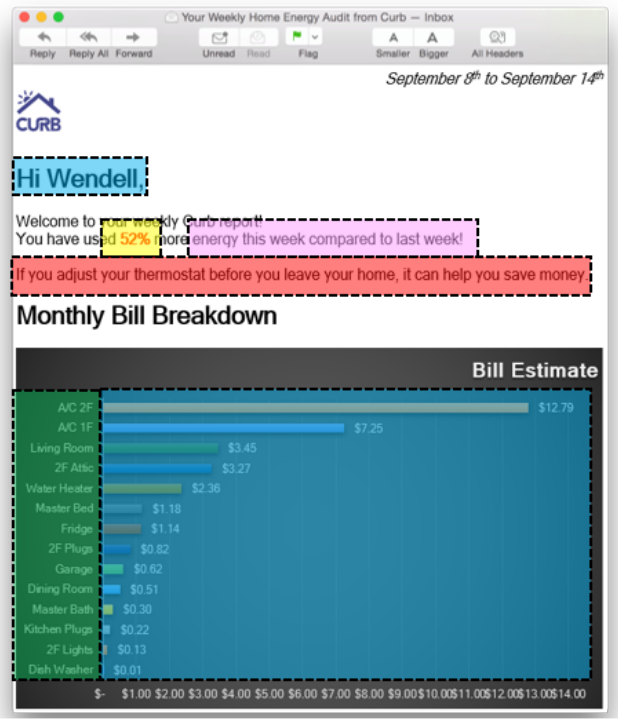
The brain data was used to create brain network analysis figures for each of the energy feedback device message formats. From this brain data, researchers were able to determine which prefrontal cortex subregion was most recruited, as well as perform different data analysis methods to justify this claim. With each prefrontal cortex subregions stems executive functions. Through these executive functions and the results from the data analysis methods, researchers are able to compare the different message formats to conclude which messages were contained more cognition, which messages were most comprehensive, and which messages were most memorable.

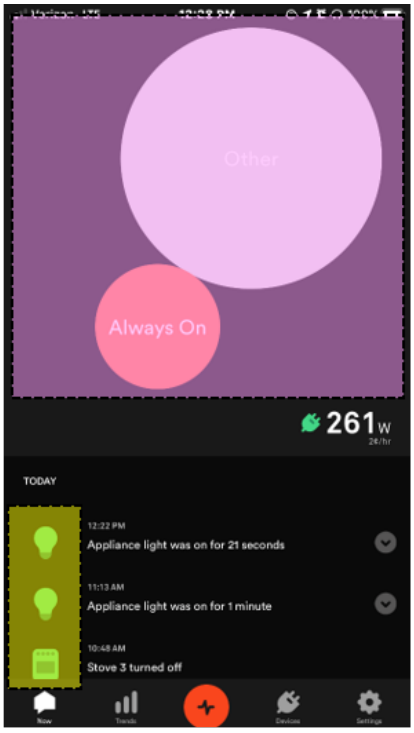
Participants were asked to wear the fNIRS device while reading feedback messages. Our sample size is specifically 30 Virginia Tech students because this study is the first of its kind and can open the door for studies with larger sample populations. This study was conducted during COVID-19, therefore, the lab contained cleaning equipment to sterilize the lab after each participant completed the experiment. After each participant completed the research experiment, the entire lab was sterilized for the next participant. We performed a literature review to formulate these energy feedback messages. The literature analysis collected information on existing energy feedback devices, their messaging capabilities, and existing message design theories to determine opportunities for improvement. Our study draws messages from energy feedback devices that are available in the market and provide whole

home energy consumption data.

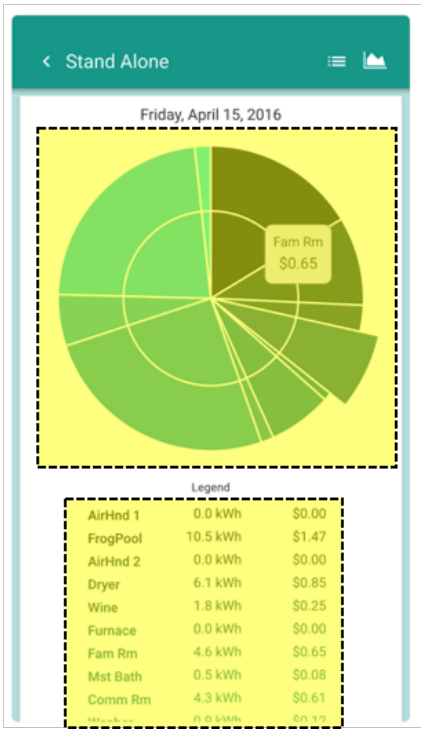
Figure 2 shows our utilization of existing message design theories such as choice architecture (Sanguinetti et al. 2018 Wilhite et al. 1995), text colour (Buchanan et al. 2014; Alahmad et al. 2012), action items, and text size (Darroch et al. 2005). To improve existing energy feedback messages, these design theories were applied. Also, our proposed feedback messages were shown to participants while wearing the fNIRS cap.

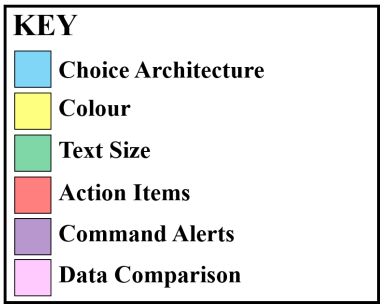
Figure 2. Updated Energy Feedback Messages


Your Weekly Home Energy Audit from Curb — Inbox
Reply
Reply All
Forward
Unread
Read
Flag
Smaller
Bigger
All Headers
September 8th to September 14th
CURB
Hi Wendell,
Welcome to your weekly Curb report!
You have used 52% more energy this week compared to last week!
If you adjust your thermostat before you leave your home, it can help you save money
Monthly Bill Breakdown
Bill Estimate
A/C 2F $12.79
A/C 1F $7.25
Living Room $3.45
2F Attic $3.27
Water Heater $2.36
Master Bed $1.18
Fridge $1.14
2F Plugs $0.82
Garage $0.62
Dining Room $0.51
Master Bath $0.30
Kitchen Plugs $0.22
2F Lights $0.13
Dish Washer $0.01
$- $1.00 $2.00 $3.00 $4.00 $5.00 $6.00 $7.00 $8.00 $9.00 $10.00 $11.00 $12.00 $13.00 $14.00


Other
Always On
261 W
TODAY
12:22 PM
Appliance light was on for 21 seconds
11:13 AM
Appliance light was on for 1 minute
10:48 AM
Stove 3 turned off


2:35
stileem@gmail.com
iMessage
Today 11:19 PM
(Alert from device eGauge50654) - To save energy, take unused plugs out of your wall sockets.
Message


Stand Alone
Friday, April 15, 2016
Fam Rm
$0.65
Legend
AirHnd 1 0.0 kWh $0.00
FrogPool 10.5 kWh $1.47
AirHnd 2 0.0 kWh $0.00
Dryer 6.1 kWh $0.85
Wine 1.8 kWh $0.25
Furnace 0.0 kWh $0.00
Fam Rm 4.6 kWh $0.65
Mst Bath 0.5 kWh $0.08
Comm Rm 4.3 kWh $0.61



3. Results

Pilot results for this research study create network analysis figures to show the relationships between the 22 fNIRS channels and the PFC subregions recruited of the 3 participants that participated in this pilot study. Our preliminary findings show that the effectiveness of existing message design theories such as choice architecture, text colour, and action items is based on the increase of brain activity. Increased brain activity relates to increased thinking and attention towards energy feedback messages, which can improve consumers willingness to purchase and utilize these energy feedback devices.

To find the correlations between the 22 fNIRS channels, PFC subregions, and feedback messages from the 4 energy feedback devices, we created brain network analysis figures, as shown in Figure 3 below. Researchers used pilot data from to ensure the messages that will be shown to the sample population for this experiment are optimal. Figure 3 below shows that the pilot study participants found messages from Sense to be the most effective because these messages produced the most brain activity.

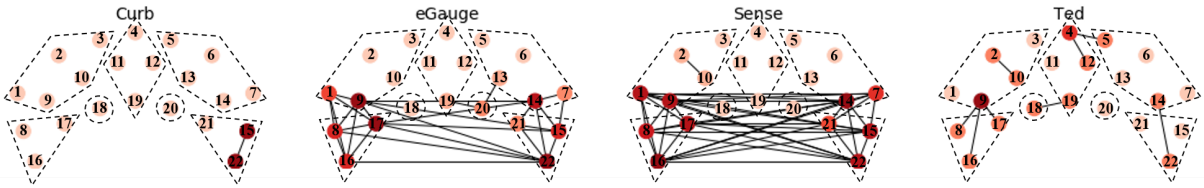


Figure 3. Preliminary Network Analyses for Selected Energy Monitors

4. Conclusions

Preliminary findings of the content analysis of energy feedback messages found that existing message design theories such as choice architecture, colour, two-way communication, customized data visualizations apply to energy feedback messages. Also, findings from our pilot study show that different message design theories apply to energy feedback messages, as well as different types of messages based on their designThis exploratory research study provides the opportunity to find the best avenue this research can thrive in. Nevertheless, with a better understanding of how energy feedback messages influence consumers brain behaviours,

message features and characteristics from theory can be capitalized on. Additionally, these improved messages can be used to target specific types of energy consumers. This study's customized energy feedback design framework can be utilized by energy researchers fill the gap between perceived and actual energy use.

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