A Neuroergonomics Approach to Evaluate the Impact of Message Framing on Consumer Decision-Making using fNIRS and EDA

Yigit Topoglu[1], Jan Watson[1], Amanda Sargent[1], Hongjun Ye[2], Rajneesh Suri[2,3], Hasan Ayaz[1,3,4,5,6]

[1] School of Biomedical Engineering, Science and Health Systems, Drexel University, Philadelphia, PA USA

[2] LeBow College of Business, Drexel University

[3] Drexel Solutions Institute, Drexel University

[4] Department of Psychology, College of Arts and Sciences, Drexel University

[5] Department of Family and Community Health, University of Pennsylvania

[6] Center for Injury Research and Prevention, Children's Hospital of Philadelphia, Philadelphia, PA USA

Decision-making is defined as the cognitive process when people choose a course of action among different alternatives based on their desires, beliefs, values, and preferences [1]. Decision-making is researched in a wide range of areas such as health [2], accounting [3], psychology [4], and marketing [5], as it is a process that people utilize in their everyday lives. Targeted messaging research aims to find the factors of a certain population by examining the characteristics of behaviors that are most impactfully affected by a specific message [6]. Targeted messaging and message framing have been widely researched in various research areas including health [7], environmental awareness [8], politics, and marketing [9]. To date, various approaches regarding the assessment of consumer behavior have relied solely on self-reported measurements such as questionnaires and surveys [10]. Although such measures are easy to implement, they are weak predictors of future behavioral changes [11; 12]. Therefore, even though some previous studies examine the relationship between message framing and consumer's decision-making [13], the effects of messaging and message framing on consumer's decision-making behavior have not yet been fully grasped.

Recent brain imaging research has shown that neural activity in the right inferior frontal gyrus (IFG) of the brain is greater when individuals are asked to make high-relative to low-conflict decisions [14; 15]. Given these studies, there is evidence to support our hypothesis, which is that the right IFG region will experience increased activation during consumer choice when decisional conflict is highly present. Alongside neuroimaging measures, electrodermal activity (EDA) has been used in decision-making research as a marker of emotional arousal [16] and a measure of decision processing with respect to increasing risk [17].

To assess the effects of messaging exposure on consumers' decision-making and preferences, we adopted a neuroergonomic approach that utilizes behavioral measurements alongside brain and body measures, which we utilized functional near-infrared spectroscopy (fNIRS) and EDA, respectively [18]. In this study, a total of 60 participants (37 female, mean age=27.6) volunteered and made binary decisions involving a fixed-rate electricity plan and 8 time-of-use (TOU) electricity plans consisting of different peak rates, non-peak rates, and duration values [19]. As seen in Figure 1a, before the experiment protocol, participants completed the consent forms and were informed about the definition of kilowatts per hour (kWh) and the tasks in the experiment. In the tasks, the fixed-rate (flat-rate) plan provided the same electricity unit rate throughout the day, while TOU plans are defined as plans that had higher unit rates during peak consumption hours and lower rates at any other hour (shown in Figure 1b). Each participant made two different choice tasks: either between two TOU plans that have different peak durations, peak rates, and non-peak rates, which was a representative of high-conflict scenario (28 decisions) (Figure 1 Panel A) or between a fixed-rate plan and a TOU plan, which was made to create a low-conflict situation (8 decisions) (Figure 1 Panel B). After making the first 36 decisions, participants were shown a one-minute video message that was either positively and negatively framed about the impact of consumers' consumption on either environment or financial-saving. The participants were separated into four different groups based on the framing and context of the message. Before and after the video, participants were instructed to relax for 30 seconds. After the rest, participants performed the same 36 binary choice tasks one more time. During the entire study, participants' brain activity over the prefrontal cortex was continuously tracked using fNIRS alongside their EDA data, and plan preferences for each question were recorded.

Throughout the experiment, prefrontal cortex hemodynamics were recorded at a sampling rate of 2 Hz by a continuous-wave fNIRS device, fNIR Imager Model 1200 (fNIR Devices LLC, fnirdevices.com) [20]. After fNIRS data acquisition, raw light intensity data was filtered with a finite impulse response (FIR), low-pass, 20^{th} order Hamming filter with a cutoff frequency of 0.1 Hz to mitigate high frequency noise. Average oxygenated and deoxygenated hemoglobin concentration values in the time-synchronized blocks of each choice task for each optode were calculated and extracted from the filtered light intensity data using Modified Beer-Lambert Law. In terms of EDA, portable and wireless sensor Shimmer GSR+ Unit (Shimmer Sensing, www.shimmersensing.com) was placed on the participants' left index and middle fingers. Participants' skin conductance was recorded at a sampling rate of 128 Hz. Using Ledalab, a MATLAB toolbox for EDA analysis [21], EDA data was filtered with a zero-phase 2_{nd} order Butterworth low-pass filter with 0.5 Hz cut-off frequency to mitigate electrical noise, and then continuous decomposition analysis, a method that uses nonnegative deconvolution to EDA data decomposition) was applied to extract phasic and tonic components of EDA [22]. Average event-related phasic EDA and HbO values for each choice block were used as features in statistical analysis using linear mixed models.

For data analysis, the hemodynamic brain activity and EDA data of participants during the choice tasks before and after the video message were compared. As seen in Figure 1c, the fNIRS results show that in TOU vs TOU choice tasks, participants brain activity over right IFG after the video significantly increases after watching negatively-framed financial-savings messages, whereas in flat rate vs TOU tasks, there were no significant interactions across all video conditions. As depicted in Figure 1d, EDA results show that both negative-framed environmental and financial-savings messaging significantly increased emotional arousal in flat rate vs TOU tasks, while as can be seen in Figure 1e, financial-saving messages affected participants' EDA levels significantly in the decisions between two TOU plans with different parameters, regardless of the framing.

The findings of the study suggest that negatively framed financial-savings messages seem to have an influence on the consumers in terms of brain activity and emotional arousal, specifically in high decisional conflict scenarios. This study demonstrates that brain and physiological measures combined provide a comprehensive assessment of consumer decisions. In addition, this study shows that EDA and fNIRS can be used in the neuroergonomic assessment of cognitive consumer decision-making behavior in real-world environments, which provides valuable information in marketing research.

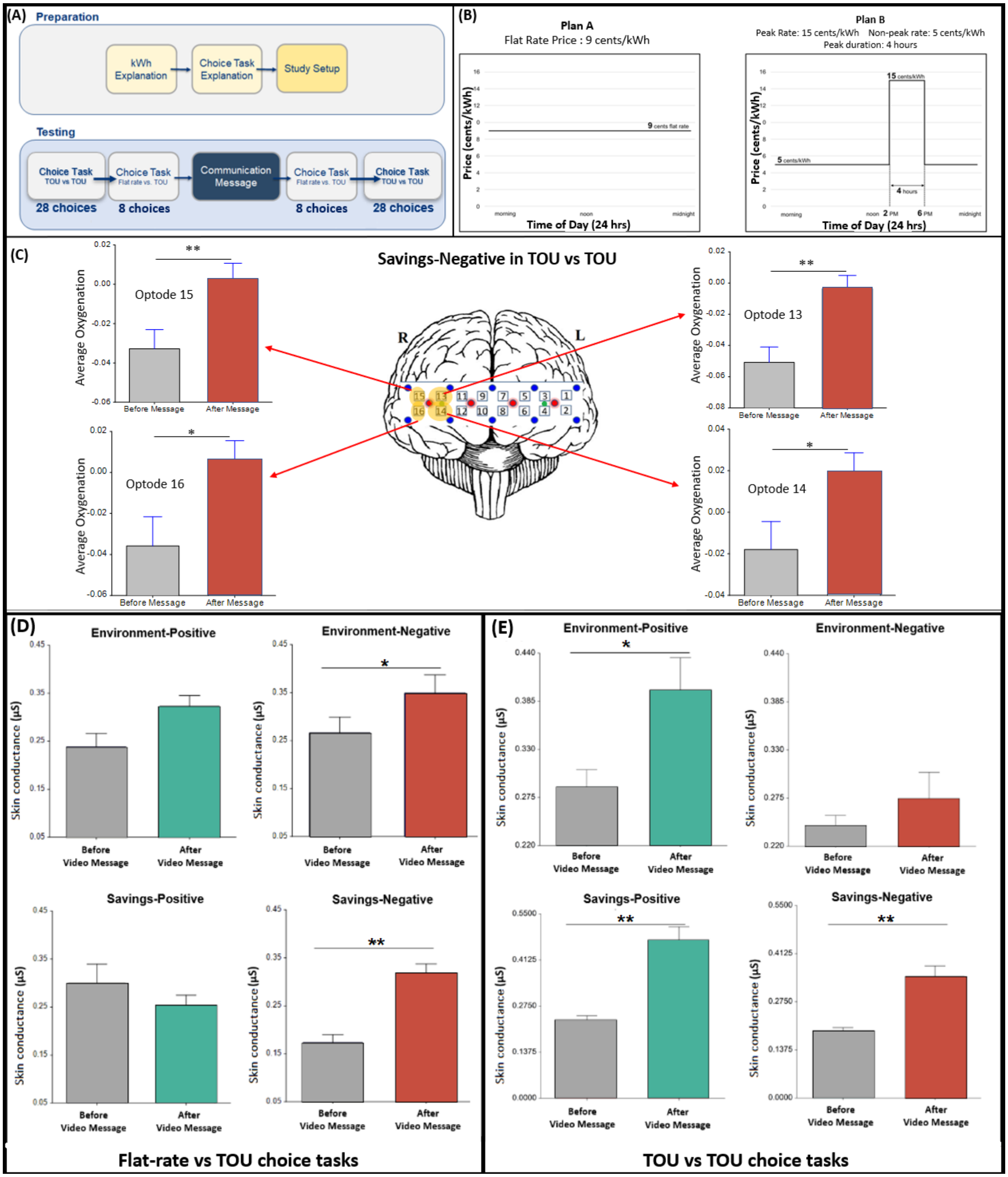

Figure 1. (a) Experimental procedure. (b) Electricity supply plans used in the study for choice tasks. Flat-rate plan (Plan A) offered the same electricity unit rate throughout the day, while TOU (time-of-use) plans (Plan B) offered higher unit rates during peak consumption hours and lower rates during other hours of the day. (c) fNIRS results for brain activity of right IFG. Results show that negatively framed financial savings video significantly affected the brain activity over the right IFG while decision-making between two plans, specifically in optode 13 ($F_{1,3163.4}$=12.31, $p < 0.01$), optode 14 ($F_{1,3214.9}$=5.29, $p = 0.02$), optode 15 ($F_{1,3097.6}$=7.39, $p < 0.01$) and optode 16 ($F_{1,3188}$=6.08, $p = 0.013$). (d) EDA results for flat rate vs TOU for each video. EDA results show that both negative-framed environmental ($F_{1,927}$=5.11, p=0.048) and financial-savings ($F_{1,956}$=18.939, p<0.01) messaging significantly increased skin conductance. (e) EDA results and TOU vs TOU choice tasks for each video. The results show both positive ($F_{1,1018}$=47.6, p<0.01) and negative ($F_{1,956}$=33.07, p<0.01) financial-saving messages significantly increased participants' skin conductance response.

References:

[1] B.A. Mellers, A. Schwartz, and A.D. Cooke, Judgment and decision making. Annual review of psychology 49 (1998) 447-477.

[2] M.M. Hunink, M.C. Weinstein, E. Wittenberg, M.F. Drummond, J.S. Pliskin, J.B. Wong, and P.P. Glasziou, Decision making in health and medicine: integrating evidence and values, Cambridge University Press, 2014.

[3] K.T. Trotman, H.C. Tan, and N. Ang, Fifty‐year overview of judgment and decision‐making research in accounting. Accounting & Finance 51 (2011) 278-360.

[4] D. Wedding, and D. Faust, Clinical judgment and decision making in neuropsychology. Archives of Clinical Neuropsychology 4 (1989) 233-265.

[5] C. Mihart, Impact of integrated marketing communication on consumer behaviour: Effects on consumer decision-making process. International Journal of Marketing Studies 4 (2012) 121.

[6] L.G. Pelletier, and E. Sharp, Persuasive communication and proenvironmental behaviours: How message tailoring and message framing can improve the integration of behaviours through self-determined motivation. Canadian Psychology/Psychologie Canadienne 49 (2008) 210.

[7] S.M. Banks, P. Salovey, S. Greener, A.J. Rothman, A. Moyer, J. Beauvais, and E. Epel, The effects of message framing on mammography utilization. Health psychology 14 (1995) 178.

[8] H. Chang, L. Zhang, and G.-X. Xie, Message framing in green advertising: The effect of construal level and consumer environmental concern. International Journal of Advertising 34 (2015) 158-176.

[9] C.T. Chang, and Y.K. Lee, Framing Charity Advertising: Influences of Message Framing, Image Valence, and Temporal Framing on a Charitable Appeal 1. Journal of Applied Social Psychology 39 (2009) 2910-2935.

[10] J. Villegas, C. Matyas, S. Srinivasan, I. Cahyanto, B. Thapa, and L. Pennington-Gray, Cognitive and affective responses of Florida tourists after exposure to hurricane warning messages. Natural Hazards 66 (2013) 97-116.

[11] C.J. Armitage, and M. Conner, Efficacy of the theory of planned behaviour: A meta‐analytic review. British journal of social psychology 40 (2001) 471-499.

[12] T.L. Webb, and P. Sheeran, Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. Psychological bulletin 132 (2006) 249.

[13] A.J. Rothman, and P. Salovey, Shaping perceptions to motivate healthy behavior: the role of message framing. Psychological bulletin 121 (1997) 3.

[14] S.I. Di Domenico, A.H. Rodrigo, H. Ayaz, M.A. Fournier, and A.C. Ruocco, Decision-making conflict and the neural efficiency hypothesis of intelligence: A functional near-infrared spectroscopy investigation. NeuroImage 109 (2015) 307-317.

[15] J.M. Jarcho, E.T. Berkman, and M.D. Lieberman, The neural basis of rationalization: cognitive dissonance reduction during decision-making. Social Cognitive and Affective Neuroscience 6 (2010) 460-467.

[16] W. Boucsein, Electrodermal activity, 2nd ed, Springer Science + Business Media, New York, NY, US, 2012.

[17] L. Holper, M. Wolf, and P.N. Tobler, Comparison of functional near-infrared spectroscopy and electrodermal activity in assessing objective versus subjective risk during risky financial decisions. NeuroImage 84 (2014) 833-842.

[18] E.T. Berkman, and E.B. Falk, Beyond brain mapping: Using neural measures to predict real-world outcomes. Current directions in psychological science 22 (2013) 45-50.

[19] A. Sargent, J. Watson, Y. Topoglu, H. Ye, W. Zhong, H. Ayaz, and R. Suri, Reliability of Consumer Choices for Conflicting Price Promotions, Springer International Publishing, Cham, 2020, pp. 103-109.

[20] H. Ayaz, P.A. Shewokis, A. Curtin, M. Izzetoglu, K. Izzetoglu, and B. Onaral, Using MazeSuite and functional near infrared spectroscopy to study learning in spatial navigation. JoVE (Journal of Visualized Experiments) (2011) e3443.

[21] M. Benedek, and C. Kaernbach, A continuous measure of phasic electrodermal activity. Journal of Neuroscience Methods 190 (2010) 80-91.

[22] M. Benedek, and C. Kaernbach, Decomposition of skin conductance data by means of nonnegative deconvolution. Psychophysiology 47 (2010) 647-658.