Accepted for publication in **APPLIED PSYCHOLOGY: AN INTERNATIONAL REVIEW**

Experiencing Range in an Electric Vehicle - Understanding Psychological Barriers

Thomas Franke, Isabel Neumann, Franziska Bühler, Peter Cocron, and Josef F. Krems

Chemnitz University of Technology

ABSTRACT

Range of electric vehicles (EVs) has long been considered a major barrier in acceptance of electric mobility. We examined the nature of how range is experienced in an EV and whether variables from other adaptation contexts, notably stress, have explanatory power for inter-individual differences in what we term comfortable range. Forty EVs were leased to a sample of users for a 6-month field study. Qualitative and quantitative analyses of range experiences were performed, including regression analyses to examine the role of stress-buffering personality traits and coping skills in comfortable range. Users appraised range as a resource to which they could successfully adapt and that satisfied most of their daily mobility needs. However, indicators were found that suggested suboptimal range utilization. Stress-buffering personality traits (control beliefs, ambiguity tolerance) and coping skills (subjective range competence, daily range practice) were found to play a substantial role in comfortable range. Hence, it may be possible to overcome perceived range barriers with the assistance of psychological interventions such as information, training and interface design. Providing drivers with a reliable usable range may be more important than enhancing maximal range in an electric mobility system.

Keywords: range, electric vehicles, field study, traffic and transport psychology, Germany

---

Address for correspondence: Chemnitz University of Technology, Department of Psychology, D-09107 Chemnitz, Germany. Email: thomas.franke [at] psychologie.tu-chemnitz.de.

This research was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. We thank our partners BMW Group and Vattenfall Europe who supported this research within the project “MINI E Berlin powered by Vattenfall”, as well as the anonymous reviewers for their very helpful comments.

Citation: Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J.F. (in press). Experiencing range in an electric vehicle - understanding psychological barriers. *Applied Psychology: An International Review.*
August 18, 2011

INTRODUCTION

How far does it go? Most often, this is one of the first questions that come into people's minds when hearing of a new electric vehicle. For most novices in the field, the perception of limited mobility resources is a barrier to purchase intentions (e.g., Bunch, Bradley, Golob, Kitamura, & Occhiuzzo, 1993; Thomas, 2010). Also, from an expert point of view, EV batteries, which essentially represent range, are often evaluated as most problematic for the success of electric mobility systems (e.g., Kitamura & Hagiwara, 2010). However, relying on existing range data drawn from travel surveys (Duke, Andrews, & Anderson, 2009; Greene, 1985) and feedback from expert EV users (Gärling, 2001; Krems, Franke, Neumann, & Cocron, 2010) EVs should easily be able to meet most travel needs. Hence, is the experience of range as barrier mainly a psychological issue?

Although EV field trials have a long-standing tradition (e.g., Bish & Tietmeyer, 1983; Patil, 1990), there is very little published research about the nature of how real users experience EV range and how they subsequently deal with it. Many field trials have focused on assessing technical variables (Francfort, et al., 1998; Goldstein, Koretz, & Harats, 1996), and few have examined overt user behavior or general user satisfaction with EVs (Eden, 1997; Francfort & Carroll, 2001). Psychological processes underlying user experience have thus far only been covered by studies with inexperienced potential users (Chéron & Zins, 1997; Kurani, Turrentine, & Sperling, 1996). In such novices, personal safety buffers have been studied as relevant variables for an anticipated interaction with range, and have been shown to increase perceived range needs (Kurani, Turrentine, & Sperling, 1994). Moreover, there is some evidence that EV users tend to underutilize given range resources (Botsford & Szczepanek, 2009; Golob & Gould, 1998). The phenomenon of range anxiety, which has been heavily discussed in the literature and public media (e.g., Rahim, 2010; Tate, Harpster, & Savagian, 2009), might contribute to this effect but only anecdotal evidence has been reported on this topic, for example, by research with EV1 users (Tate, et al., 2009). In sum, scientific knowledge of range experience in real users is scarce

The objective of the present research was to achieve a better understanding of range experience in experienced EV drivers. This was done by applying a field trial approach with 40 EVs leased to customers from the general public, for a 6-month period. On the basis of the existing literature we formulated the concept of comfortable range and related it to theories of stress and self-regulation. To meet the research objective we examined (1) the prominent conceptual dimensions of range experience, (2) quantitative indicators of range experience in terms of range satisfaction and concerns, as well as comfortable range, and (3) the role of stress-buffering personality traits and coping skills in comfortable range. The practical aim of this research is to

Citation: Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J.F. (in press). Experiencing range in an electric vehicle - understanding psychological barriers. *Applied Psychology: An International Review.*
August 18, 2011

provide alternative ways of dealing with the generally perceived barrier imposed by the experience of range, aside from exclusively improving battery performance. With knowledge of how users experience and interact with range, user training and design of the human machine interface (HMI) could be improved.

Psychological Range Levels in an EV

CONCLUSIONS

The range of EVs has long been considered a major barrier to public acceptance of electric mobility. However, for state-of-the-art electric mobility systems our evidence suggests that range is primarily a psychological barrier. However, this does not imply that range in electric mobility systems can be dismissed, especially if we take environmental utility and pricing issues into consideration. The present study attempted to broaden as well as shift the focus of conventional research, from increasing nominal battery capacity to focusing on enhancing usable range. Understanding individual range experience dynamics and proposing ideas for supportive interventions were efforts in this direction.

To support the feasibility of this approach, we introduced a relevant variable for range experience – comfortable range – merging variables discussed in previous research, namely, range buffers and range anxiety. This proposed variable was contextualized in four psychological range levels. We present a first attempt to theoretically define the variable of comfortable range within the broader theoretical framework of stress and general control theory. Viable strategies to improve range experience may be devised from this outline, to ensure the successful development of future electric mobility systems.

Citation: Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J.F. (in press). Experiencing range in an electric vehicle - understanding psychological barriers. *Applied Psychology: An International Review.*
August 18, 2011

REFERENCES

Beier, G. (1999). Kontrollüberzeugungen im Umgang mit Technik [Control beliefs in dealing with technology]. *Report Psychologie, 9*, 684-693.

Beier, G., Spiekermann, S., & Rothensee, M. (2006). Die Akzeptanz zukünftiger Ubiquitous Computing Anwendungen [Acceptance of future ubiquitous computing applications]. In H. M. Heinecke & H. Paul (Eds.), *Mensch & Computer 2006: Mensch und Computer im Strukturwandel* (pp. 145-154). Munich, Germany: Oldenbourg Verlag.

Bish, J. R., & Tietmeyer, G. P. (1983). Electric vehicle field test experience. *IEEE Transactions on Vehicular Technology, VT-32*(1), 81-89.

Botsford, C., & Szczepanek, A. (2009). *Fast charging vs. slow charging: Pros and cons for the new age of electric vehicles*. Paper presented at the EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium Stavanger.

Bowers, K. S. (1973). Situationism in psychology: An analysis and a critique. *Psychological Review, 80*(5), 307-336.

Bunch, D. S., Bradley, M., Golob, T. F., Kitamura, R., & Occhiuzzo, G. P. (1993). Demand for clean-fuel vehicles in California: A discrete-choice stated preference pilot project. *Transportation Research Part A, 27*(3), 237-253.

Carver, C. S., & Scheier, M. F. (1998). *On the self-regulation of behavior*. New York, NY: Cambridge University Press.

Chéron, E., & Zins, M. (1997). Electric vehicle purchasing intentions: The concern over battery charge duration. *Transportation Research Part A: Policy and Practice, 31*(3), 235-243.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Oxford, England: M.I.T. Press.

Cocron, P., Bühler, F., Neumann, I., Franke, T., Krems, J. F., Schwalm, M., et al. (in press). Methods of evaluating electric vehicles from a user's perspective - the MINI E field trial in Berlin. *IET Intelligent Transport Systems*.

Connor-Smith, J. K., & Flachsbart, C. (2007). Relations Between Personality and Coping: A Meta-Analysis. *Journal of Personality and Social Psychology, 93*(6), 1080-1107.

Contrada, R. J., & Baum, A. (2009). *The Handbook of Stress Science: Biology, Psychology, and Health*. New York: Springer.

Dalbert, C. (1999). Die Ungewissheitstoleranzskala: Skaleneigenschaften und Validierungsbefunde [Tolerance of Ambiguity Scale: Scale Characteristics and Validity] (Hallesche Berichte zur Pädagogischen Psychologie Nr. 1). Halle, Germany: Martin-Luther-Universität Halle-Wittenberg, Institut für Pädagogik. .

Citation: Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J.F. (in press). Experiencing range in an electric vehicle - understanding psychological barriers. *Applied Psychology: An International Review.*
August 18, 2011

Duke, M., Andrews, D., & Anderson, T. (2009). The feasibility of long range battery electric cars in New Zealand. *Energy Policy, 37*(9), 3455-3462.

Eden, T., Heber, C., Höpfner,U., & Voy, C. (1997). Erprobung von Elektrofahrzeugen der neuesten Generation auf der Insel Rügen [Testing electric vehicles of the latest generation on the Island Rügen]. *Automobiltechnische Zeitschrift, 9*, 537-550.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149-1160.

Francfort, J. E., Bassett, R. R., Briasco, S., Culliton, W., Duffy, E. F., Emmert, R. A., et al. (1998). Site Operator Program Final Report (INEEL/EXT-97-01383). Idaho Falls, Idaho: Idaho National Engineering and Environmental Laboratory.

Francfort, J. E., & Carroll, M. (2001). Field operations program. Neighborhood electric vehicle fleet use (INEEL/EXT-01-00864). Idaho Falls, Idaho: Idaho National Engineering and Environmental Laboratory.

Franke, T., Bühler, F., Cocron, P., Neumann, I., & Krems, J. F. (2011). *Enhancing sustainability of electric vehicles: A field study approach to understanding user acceptance and behavior*. Manuscript submitted for publication.

Frenkel-Brunswik, E. (1949). Intolerance of ambiguity as an emotional and perceptual personality variable. *Journal of Personality, 18*, 108-143.

Frensch, P. A., & Funke, J. (1995). *Complex problem solving: The European perspective*. Hillsdale, NJ England: Lawrence Erlbaum Associates, Inc.

Frone, M. R. (1990). Intolerance of ambiguity as a moderator of the occupational role stress-strain relationship: A meta-analysis. *Journal of Organizational Behavior, 11*(4), 309-320.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis and Prevention, 37*(3), 461-472.

Furnham, A., & Ribchester, T. (1995). Tolerance of ambiguity: A review of the concept, its measurement and applications. *Current Psychology, 14*(3), 179-199. doi: 10.1007/bf02686907

Gaab, J., Jucker, P., Staub, F., & Ehlert, U. (2005). Mind over matter: Psychobiological effects of exposure therapy in arachnophobia [Mind over matter: Psychobiologische Effekte einer Konfrontationstherapie bei Spinnenangst]. *Zeitschrift für Klinische Psychologie und Psychotherapie, 34*(2), 121-132.

Gärling, A. (2001). Paving the way for the electric vehicle (VR 2001:01). Stockholm, Sweden: VINNOVA.

Gescheider, G. A. (1997). *Psychophysics: the fundamentals* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum.

Goldstein, J. R., Koretz, B., & Harats, Y. (1996, 11-16 Aug 1996). *Field test of the Electric Fuel™ zinc-air refuelable battery system for electric vehicles.* Paper presented at the Energy Conversion Engineering Conference, 1996. IECEC 96. Proceedings of the 31st Intersociety.

Golob, T. F., & Gould, J. (1998). Projecting use of electric vehicles from household vehicle trials. *Transportation Research Part B: Methodological, 32*(7), 441-454.

Greco, V., & Roger, D. (2003). Uncertainty, stress and health. *Personality and Individual Differences, 34*, 1057-1068.

Greene, D. L. (1985). Estimating daily vehicle usage distributions and the implications for limited-range vehicles. *Transportation Research Part B, 19*(4), 347-358.

Gregersen, N. P., & Berg, H. Y. (1994). Lifestyle and accidents among young drivers. *Accident Analysis and Prevention, 26*(3), 297-303.

Gulian, E., Matthews, G., Glendon, A. I., Davies, D. R., & Bedney, L. M. (1989). Dimensions of driver stress. *Ergonomics, 32*(6), 585-602.

Hammerfald, K., Eberle, C., Grau, M., Kinsperger, A., Zimmermann, A., Ehlert, U., et al. (2006). Persistent effects of cognitive-behavioral stress management on cortisol responses to acute stress in healthy subjects - A randomized controlled trial. *Psychoneuroendocrinology, 31*(3), 333-339.

Hastie, R., & Dawes, R. M. (2009). *Rational choice in an uncertain world: The psychology of judgment and decision making* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Holahan, C. J., & Moos, R. H. (1990). Life Stressors, Resistance Factors, and Improved Psychological Functioning: An Extension of the Stress Resistance Paradigm. *Journal of Personality and Social Psychology, 58*(5), 909-917.

Holland, C., Geraghty, J., & Shah, K. (2010). Differential moderating effect of locus of control on effect of driving experience in young male and female drivers. *Personality and Individual Differences, 48*(7), 821-826.

Keinath, A., & Schwalm, M. (2010). *Are there differences in the mobility patterns due to BEV?* Paper presented at the 27. International Congress of Applied Psychology, Melbourne.

Kitamura, M., & Hagiwara, Y. (2010, May 18). Honda 'Lacks Confidence' in Electric-Car Demand, *Bloomberg.com*. Retrieved from http://www.bloomberg.com/apps/news?pid=newsarchive&sid=a_kxOOLkD.cU

König, S., & Dalbert, C. (2004). Ungewissheitstoleranz, Belastung und Befinden bei Berufsschullehrerlnnen [Uncertainty tolerance, stress and well-being in teachers at vocational schools]. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie, 36*(4), 190-199.

Krems, J. F., Franke, T., Neumann, I., & Cocron, P. (2010). Research methods to assess the acceptance of EVs - experiences from an EV user study. In T. Gessner (Ed.), *Smart Systems Integration: 4th European Conference & Exhibition on Integration Issues of Miniaturized Systems - MEMS, MOEMS, ICs and Electronic Components. Como, Italy*. Berlin, Germany: VDE Verlag.

Kruse, R. E., & Huls, T. A. (1973). Development of the federal urban driving schedule. *SAE Prepr*(730553).

Kunert, U., & Follmer, R. (2005). Methodological advances in national travel surveys: Mobility in Germany 2002. *Transport Reviews, 25*(4), 415-431.

Kurani, K. S., Turrentine, T., & Sperling, D. (1994). Demand for electric vehicles in hybrid households: an exploratory analysis. *Transport Policy, 1*(4), 244-256.

Kurani, K. S., Turrentine, T., & Sperling, D. (1996). Testing electric vehicle demand in 'hybrid households' using a reflexive survey. *Transportation Research Part D: Transport and Environment, 1*(2), 131-150.

Lazarus, R., S., & Folkman, S. (1984). *Stress, appraisal and coping*. New York: Springer.

Levenson, H. (1972). Distinctions within the concept of internal-external control: Development of a new scale. *Proceedings of the Annual Convention of the American Psychological Association, 7*(Pt. 1), 261-262.

Leventhal, H., Halm, E., Horowitz, C., Leventhal, E. A., & Ozakinci, G. (2004). Living with chronic illness: A contextualized, self-regulation approach. In S. Sutton, A. Baum & M. Johnston (Eds.), *The Sage handbook of health psychology* (pp. 197–240). Thousand Oaks, CA: Sage.

Miller, G. A., Galanter, E., & Pribram, K. H. (1960). *Plans and the structure of behavior*. New York, NY US: Henry Holt and Co.

Neumann, I., Cocron, P., Franke, T., Bühler, F., Wege, C., & Krems, J. F. (2010). *Begrenzte Reichweite von Elektrofahrzeugen: Wie können Fahrer durch Anzeigenkonzepte unterstützt werden? [Limited range of electric vehicles - How can driver be supported by display concepts?]*. Paper presented at the 52. Tagung experimentell arbeitender Psychologen, Saarbrücken.

Patil, P. G. (1990). Prospects for electric vehicles. *IEEE Aerospace and Electronic Systems Magazine, 5*(12), 15-19.

Rahim, S. (2010, May 7). Will lithium-air battery rescue electric car drivers from 'range anxiety'? , *The New York Times*. Retrieved from http://www.nytimes.com/cwire/2010/05/07/07climatewire-will-lithium-air-battery-rescue-electric-car-37498.html

Romm, J. J., & Frank, A. A. (2006). Hybrid vehicles gain traction. *Scientific American, 294*(4), 72-79.

Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. *Psychological monographs, 80*(1), 1-28.

Stade, M., Meyer, C., Niestroj, N., & Nachtwei, J. (2011). *(Not) everybody's darling: Value and prospects of multiple linear regression analysis and assumption checking*. Manuscript submitted for publication.

Steg, L. (2005). Car use: Lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice, 39*(2-3 SPEC. ISS.), 147-162.

Strauss, A., & Corbin, J. M. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*: Thousand Oaks, CA, US: Sage Publications, Inc.

Tate, E. D., Harpster, M. O., & Savagian, P. J. (2009). The Electrification of the Automobile: From Conventional Hybrid, to Plug-in Hybrids, to Extended-Range Electric Vehicles. *SAE International Journal of Passenger Cars - Electronic and Electrical Systems, 1*(1), 156-166.

Thomas, D. (2010, May 04). Poll: Most consumers wary of electric cars' limited range, *USA Today*. Retrieved from http://content.usatoday.com/communities/driveon/post/2010/05/poll-most-consumers-wary-of-electric-cars-limited-range/1

Wilde, G. J. S. (1982). The theory of risk homeostasis: Implications for safety and health. *Risk Analysis, 2*(4), 209-225.

Young, K. L., Regan, M. A., Triggs, T. J., Jontof-Hutter, K., & Newstead, S. (2010). Intelligent speed adaptation-Effects and acceptance by young inexperienced drivers. *Accident Analysis and Prevention, 42*(3), 935-943.

Citation: Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J.F. (in press). Experiencing range in an electric vehicle - understanding psychological barriers. *Applied Psychology: An International Review.*
August 18, 2011