Know-how or Know-why? The Role of Hybrid Electric Vehicle Drivers' Acquisition of Eco-Driving Knowledge for Eco-Driving Success

Matthias G. Arend[a*], Thomas Franke[b], Neville A. Stanton[c]

Abstract: Hybrid electric vehicles (HEVs) can contribute to sustainable transport. Yet, their real-world energy efficiency depends on HEV drivers' eco-driving behaviour. Eco-driving knowledge is key for successful eco-driving. The present research focused on the role of perceived strategy knowledge (know-how) versus technical system knowledge (know-why) in a study with 121 HEV drivers. The relationship between knowledge components and knowledge acquisition processes, as well as fuel efficiency, were examined. Structural equation modelling results indicated that perceived strategy knowledge was related to acquisition by testing (i.e., interacting with the vehicle and its interfaces) and reading (i.e., manuals, books and websites) while technical system knowledge was only related to acquisition by reading. In contrast to technical system knowledge, perceived strategy knowledge was no significant predictor of fuel efficiency. The results indicated that emphasis should be put into promoting technical system knowledge (e.g., by tutoring systems) to support motivated drivers' in achieving higher fuel efficiency.

Keywords: Eco-driving, knowledge acquisition, user-energy interaction.

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Highlights:

- Hybrid electric vehicle drivers' eco-driving knowledge acquisition was studied
- Technical system knowledge (know-how) was acquired by reading
- Strategy knowledge was acquired by reading and on-the-road testing of strategies
- Only technical system knowledge was significantly related to higher fuel efficiency
- System feedback should thus facilitate the acquisition of the relevant know-how

[a]Institute of Psychology, RWTH Aachen University, Aachen, Germany
[b]Engineering Psychology and Cognitive Ergonomics, Institute for Multimedia and Interactive Systems, Universität zu Lübeck, Lübeck, Germany
[c]Transportation Research Group, Faculty of Engineering and the Environment, University of Southampton, Southampton, UK
*Jägerstraße 17-19, 52066 Aachen, Germany; e-mail: matthias.georg.arend@rwth-aachen.de

1 INTRODUCTION

Global CO2 emissions caused by road transport are among the major impediments to the reduction of greenhouse gases (Davis et al., 2010), which is vital to address climate change (Solomon et al., 2009). In this respect, a shift towards more energy efficient vehicles, such as (hybrid) electric vehicles, has been regarded as promising (Bitsche and Gutman, 2004; Ida et al, 2014). Although these vehicles provide an advantage compared to conventional vehicles, their real-world energy efficiency strongly depends on how they are driven by users (af Wåhlberg, 2007; Barkenbus, 2010; Bingham et al., 2012). Driving behaviour that is targeted towards increasing fuel efficiency is one of the most important aspects of eco-driving (operational eco-driving; Sivak and Schoettle, 2012), which in general describes all those influences that drivers have on the energy consumption of their vehicles (see e.g., Barkenbus. 2010; Jamson et al., 2015b; Sanguinetti et al., 2017; Sivak and Schoettle, 2012).

For advancing knowledge on user-energy interaction, studying eco-driving in hybrid electric vehicles (HEVs) constitutes a particularly relevant field. This is due to the complexity of the HEV powertrain that is characterized by an electric motor as well as a combustion engine and the bidirectional energy flow between the wheels and the battery introduced by regenerative braking (McIlroy et al., 2013; Cocron et al., 2013). Indeed, it has been shown that technical system knowledge as well as the selection and implementation of specific eco-driving strategies are major factors for achieving optimal energy efficiency with HEVs (Arend and Franke, 2017; Franke et al., 2016). This emphasizes the important role eco-driving knowledge plays for drivers' success (or failure) to drive in a fuel-efficient manner.

The role of factors such as eco-driving motivation and eco-driving knowledge for drivers' eco-driving behaviour on individual trips has been studied extensively (e.g., McIlroy and Stanton, 2017; Neumann et al., 2015; Stillwater and Kurani, 2013). Yet, there is a lack of quantitative research about how HEV drivers acquire their eco-driving knowledge and how these acquisition processes relate to day-to-day fuel efficiency. A first step in this agenda was to conduct an interview study (Franke et al., 2017a), which indicated that drivers acquired their eco-driving knowledge via two ways. Firstly, by monitoring system feedback in real time (Franke et al., 2017; for similar findings see also McIlroy et al., 2017; Stillwater and Kurani, 2013). Secondly, via external sources, such as gathering information about the HEV system or eco-driving strategies via internet forums (Franke et al., 2017a).

Building upon this, the present research seeks to quantify (a) how drivers use different acquisition means to acquire eco-driving knowledge, (b) how these eco-driving knowledge types relate to fuel efficiency and (c) how these acquisition processes relate to trip-level fuel efficiency. This understanding is particularly important because it can contribute to an advanced theoretical framework of eco-driving and, from the perspective of green ergonomics (Hanson, 2013; Thatcher, 2013), to an advanced design of eco-driving support systems that can help drivers in gathering the important eco-driving knowledge that promotes eco-driving success.

2 BACKGROUND

2.1. Eco-driving Knowledge: A Control-Theoretic Approach

Implementing eco-driving strategies is a task that affords continuous control and monitoring of the vehicle, the traffic and the driving environment (Dogan et al., 2011; Franke et al., 2016). Such aspects of driving behaviour can be modelled particularly well with control-theoretic frameworks (Fuller, 2005, 2011; Summala, 2007; Zhang and Kaber, 2013). These models of driving behaviour assume, parallel to self-regulation theory (Carver and Scheier, 1998) and other control theoretic conceptions, that an actual system state is continuously compared to a target system state and drivers implement behaviours to adapt the actual state to the target state (in the case of the present research, use of eco-driving strategies; Franke et al., 2016; for comparable conceptualisations of behavioural adaption for safe driving see e.g. Melman et al., 2017).

To select an eco-driving strategy (i.e., one or more target system states), eco-driving knowledge is used. It can be conceptualized that all available eco-driving strategies are mentally represented in a strategy knowledge base (like schemata or mental models, see Pampel et al., 2018; Plant and Stanton, 2013; Revell and Stanton, 2014) together with a subjective evaluation of the influence of each strategy on energy efficiency (see Franke et al., 2016). The perceived usefulness of this strategy knowledge base to achieve higher energy efficiency can be summarized as *perceived strategy knowledge*. That is, the degree to which drivers assume that their conceptualizations of eco-driving strategies are appropriate to achieve higher fuel efficiency. From the perspective of acquisition processes, it is a key question how the interaction with the vehicle, or the specific search for information (e.g., in books or on websites; Franke et al., 2017a), produce the conceptualizations that constitute a high or low perceived strategy knowledge (which is the first component of eco-driving knowledge).

The second general component of eco-driving knowledge is *technical system knowledge*, which is the knowledge about the HEV system and its energy dynamics (Arend and Franke, 2017). Drivers with a high degree of this type of knowledge are able to understand *why* (i.e., because of which processes in the HEV system) certain eco-driving strategies might be energy efficient or not. This should enable them to adapt their eco-driving strategies more adequately to dynamic and varying driving conditions (which indicates that technical system knowledge should directly influence eco-driving success). Note that, in contrast to the rather procedural character of strategy knowledge (perceived knowledge of *what* to do), technical system knowledge is rather declarative knowledge (factual knowledge and information; Anderson, 1982). For example, drivers with high perceived strategy knowledge for accelerations should believe that they know *how* the accelerator pedal should be used to accelerate energy efficiently, whereas drivers with high technical system knowledge should know *why* the system operates efficiently when this strategy is applied.

Finally, further inter-individual differences between drivers determine differences in eco-driving behaviour and, thus, eco-driving success. The most prominent of these is eco-driving motivation. Compared to drivers with low eco-driving motivation, highly motivated drivers will more likely prioritize the goal of driving energy efficient to other driving goals (e.g., Dogan et al., 2011; Fuller, 2007).

For technical system knowledge as well as eco-driving motivation, a positive relationship with fuel efficiency has been established in previous research (Arend and Franke, 2017; Franke et al., 2016). Consequently, the first research question (Q1) of the present research is how perceived strategy knowledge is related to fuel efficiency.

2.2. Acquisition of Eco-Driving Knowledge

The process of driving and the shorter-term processes determining eco-driving behaviour have already been described. Longer-term knowledge acquisition processes in which eco-driving knowledge is acquired (Helmbrecht et al., 2014; Neumann et al., 2015; Pichelmann et al., 2013) are however also hypothesized to be relevant for driving behaviour (e.g., Mansfield et al., 2016).

Previous results regarding the acquisition of eco-driving knowledge in a sample of HEV drivers with above average fuel efficiency and higher motivation to drive fuel efficient (i.e., qualitative analysis; Franke et al., 2017a) indicated that the most prominent methods that drivers used to acquire eco-driving knowledge by interacting with the HEV were the systematic testing of driving behaviours yielding lower or higher fuel consumption (*acquisition by testing*; e.g., by comparing the energy efficiency of different eco-driving strategies on the same route under similar conditions) and the monitoring of different kinds of system feedback (*acquisition by monitoring*). It should be noted that both acquisition strategies can be assumed to have common (e.g., monitoring of momentary fuel consumption during systematic testing) as well as separate components (e.g., one can monitor the system feedback by driving without testing eco-driving strategies systematically). Without interaction with the HEV, most drivers used manuals, internet forums or books to acquire eco-driving knowledge by reading (*acquisition by reading*).

Considering the acquisition of eco-driving knowledge, the research questions in the present research were thus how the three acquisition types relate to perceived strategy knowledge (Q2), technical system knowledge (Q3), eco-driving motivation (Q4) and, finally, fuel efficiency (mediated by eco-driving knowledge; Q5).

3 PRESENT RESEARCH AND HYPOTHESES

The objective of the present research was to quantify (a) how acquisition by testing, monitoring and reading relates to perceived strategy knowledge and technical system knowledge, (b) how both knowledge types relate to fuel efficiency and (c) how the acquisition types relate to eco-driving success (mediated by eco-driving knowledge). For that, five research questions (Q1-Q5) have been deduced based on which hypotheses are formulated below. Those relationships were tested with a structural equation model (SEM) and are depicted in the study framework (see Figure 1). Assumptions about all relationships are specified in this framework as well as direct and indirect relationships between variables. Note that this model is not a theoretical framework (such as the control theoretic model) but a study framework for the present research.

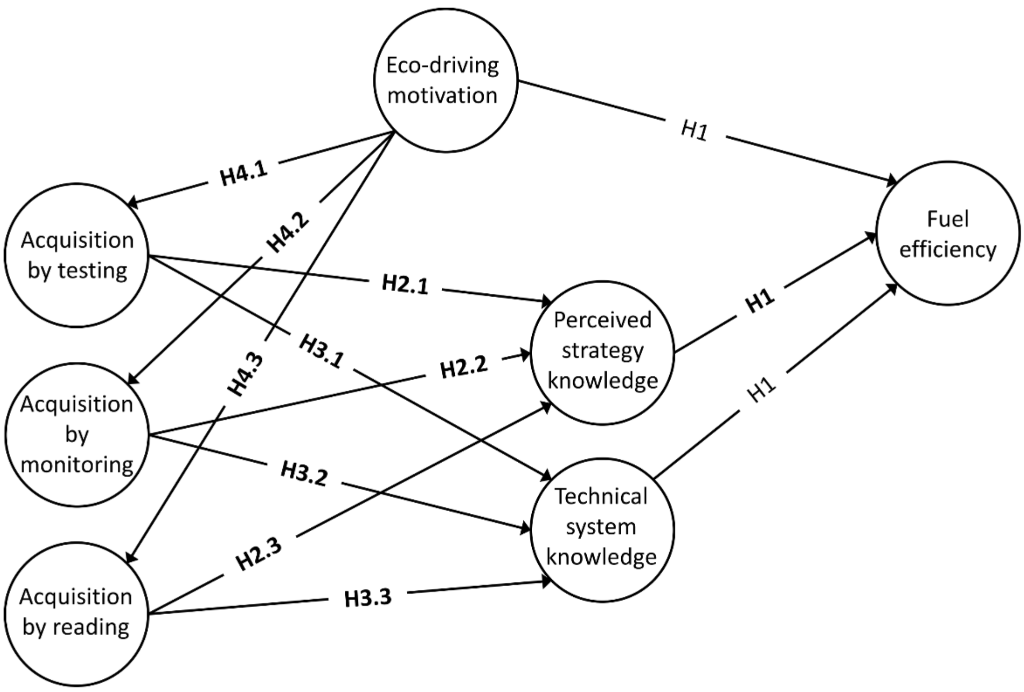

Figure 1. Study framework.

Considering Q1, it can be hypothesized that perceived strategy knowledge is positively related to fuel efficiency (H1). This relationship should persist when the positive effects of technical system knowledge and eco-driving motivation, already identified for the present sample (Arend and Franke, 2017), are also taken into account.

Regarding Q2 and Q3, the acquisition of perceived strategy and technical system knowledge, results from the previous interview study (Franke et al., 2017a) indicated that drivers used testing, monitoring and reading to acquire both eco-driving knowledge types. Consequently, it can be hypothesized that perceived strategy knowledge is positively related to acquisition by testing (H2.1), acquisition by monitoring (H2.2) and acquisition by reading (H2.3). On the other hand, technical system knowledge is also hypothesized to be positively related to acquisition by testing (H3.1), acquisition by monitoring (H3.2) and acquisition by reading (H3.3). Note that all hypotheses are directional here.

Regarding Q4, the relationship of eco-driving motivation to all three acquisition types, it is expected that more motivated drivers do more to acquire eco-driving knowledge (based on the results reported in Franke et al., 2017a). Consequently, acquisition by testing (H4.1), acquisition by monitoring (H4.2) and acquisition by reading (H4.3) are hypothesized to relate positively to eco-driving motivation.

Finally, considering Q5, it is hypothesized that the different acquisition types have indirect and total effects on fuel efficiency, mediated by eco-driving knowledge. This means that higher use of one of the acquisition types should relate to perceived strategy and/or technical system knowledge which relate to fuel efficiency. The sum of positive relationships determines the total effect (e.g., a positive relationship via perceived strategy as well as technical system knowledge would result in a combined positive effect of these positive relationships).

4 METHOD

4.1. Participants

To examine eco-driving knowledge acquisition processes, it is necessary to study a sample of experienced HEV drivers. Consequently, HEV drivers were recruited via the online database spritmonitor.de (the website allows to log the fuel consumption by entering refuelling events to the database). Drivers of the Toyota Prius 2, Prius 3 and Prius c, as particularly prototypical HEVs, took part. A second inclusion criterion for drivers was that they had logged at least one refuelling event within 6 months before the study (yet, most drivers logged their fuel consumption on a weekly basis). Finally, only drivers capable of understanding German were included. Note that the present research was part of a larger research project that assesses how HEV eco-drivers develop, implement and conceptualize their eco-driving strategies from the perspective of user-energy interaction. In this research project, an interview study was conducted (Franke et al., 2016), followed by a large-scale questionnaire study (Arend and Franke, 2017) which also involved the present research. Data from the latter study was used for this paper.

The final sample was composed of a total of *N* = 121 HEV drivers (93% male; with a mean age of 48 years, *SD* = 11), of whom 42% drove a Prius 3, 30% a Prius c, and 28% a Prius 2 as their most-used HEV. 20 of the participants had already participated in an interview-study (Franke et al., 2016) before taking part in the present study. Drivers had a mean driving experience with HEVs in general of 62,392 km (SD = 52,324; range = 5,600–250,000), which they had gathered in M = 3.3 years (SD = 2.3; range = 0.4-16).

4.2. Scales and Measures

All items were assessed with the same rating scale (a 6-point Likert scale ranging from completely disagree [1] to completely agree [6]) and can be found in the Appendix A.

4.2.1. Technical System Knowledge

Technical system knowledge was assessed with a three-item scale that has been developed and employed in previous research (Arend and Franke, 2017; Franke et al., 2016). Each of the three items (adapted from Franke et al., 2015) represents knowledge concerning the HEV system and its energy dynamics.

4.2.2. Perceived Strategy Knowledge

To adequately assess perceived strategy knowledge, a three-item scale was constructed parallel to the approved technical system knowledge scale. The items capture the degree to which drivers believe that they know how to eco-drive (i.e., their perceived capability to control the vehicle in order to achieve higher fuel efficiency).

4.2.3. Eco-Driving Motivation

The two items assessing eco-driving motivation, also developed and employed in previous research (Arend and Franke, 2017; Franke et al., 2016), were constructed to represent the behavioural intention to drive energy efficient (e.g., Ajzen, 1991; Franke et al., 2017b; Lauper et al., 2015).

4.2.4. Fuel Efficiency

To achieve an accurate and standardized indicator of fuel efficiency, drivers were requested to estimate their average fuel consumption for April 2015 to September 2015 because regional variations in fuel efficiency can be assumed to be particularly large in winter conditions (estimated fuel consumption). Furthermore, they were asked to provide their logged fuel consumption data for the same period (logged fuel consumption; provided by 100 participants). The correlation coefficient of both measures was computed to assess the driver's general estimation accuracy, which can be considered as good based on the revealed strong relationship of both (r = .86, see: Arend and Franke, 2017).

To control for possible influences of drivers' individual trip profiles on fuel consumption (e.g., some drivers may mostly drive on urban, others mostly on rural routes), the participants were asked to estimate their fuel consumption for two standardized scenarios, one representing an urban and one a rural route. Furthermore, the influence of the specific vehicle model on fuel consumption had to be controlled (e.g., the different Prius model have variations in general system fuel efficiency due to differences in weight, drag coefficient, and powertrain). Consequently, the fuel efficiency indicators were standardized based on the distribution parameters (mean and standard deviation) that were obtained from spritmonitor.de for each Prius model (i.e. extracted data of >1200 vehicles). These two standardized fuel efficiency indicators were used for the SEM analysis reported below.

4.2.5. Acquisition by Testing, Monitoring and Reading

The three acquisition types were assessed by a scale consisting of six items in which each acquisition type was represented by two items. To determine if the three acquisition types were sufficiently distinct, a principal axis factor analysis was performed with all six items. The eigenvalues and the scree-plot indicated that a three-factor solution with two items per sub-scale fitted the data structure best. For the rotated factor solution, all except of one (r = .41 for the monitoring sub-scale with one of the two items) correlations of the items with their respective factor were large (r > .73; more information on factor loadings can be found in the results section). Consequently, a three-factor solution distinguishing the three acquisition types received sufficient support.

The first pair of items assessed the type of knowledge acquisition that arises from testing and studying the energy efficiency of different driving behaviours (termed *acquisition by testing*), the second pair of items assessed the degree to which the acquisition of strategy knowledge depends on the monitoring of system feedback provided by the HEV (termed *acquisition by monitoring*) and the third pair of items assessed the acquisition of knowledge based on reading in manuals, books or on websites (termed *acquisition by reading*).

5 RESULTS

The specified hypotheses were analysed with a SEM based on the R-package ‘lavaan’ (Rosseel, 2012). In general, structural equation analyses contain observed variables (here: the items as well as the fuel efficiency indicators) as well as latent variables (here: eco-driving motivation, perceived strategy and technical system knowledge as well as the three acquisition types) which are derived from the observed variables (comparable to factor analysis). Furthermore, several regressions that specify relationships (paths) between different variables can be estimated in one model (Wolf, Harrington, Clark, & Miller, 2013). Consequently, all relationships depicted in Figure 1 were analysed as follows: (a) fuel efficiency was regressed on perceived strategy knowledge, technical system knowledge, and eco-driving motivation; (b) perceived strategy knowledge and technical system knowledge were regressed on the three acquisition types; (c) each of the three acquisition types was regressed on eco-driving motivation. Additionally, the correlation of perceived strategy and technical system knowledge was also included in the model.

Note that, if necessary, items were inverted before they were entered into the analysis. No univariate outliers in the latent variables were identified by the Grubbs Test (Grubbs, 1950). The maximum likelihood method was used for parameter estimation. Because all scales were composed of three or two items, parallel and (essentially) measurement models were fitted to each scale (for an overview of these models, see Graham, 2006). The measurement model with the best fit (i.e., most adequate way to combine items to one scale) was selected which was the essentially tau-equivalent one for all scales. Accordingly, the reliability (as Cronbach’s α; Graham, 2006) was computed for each of these scales (see Table 1). All scales except of the acquisition by monitoring scale achieved acceptable reliabilities. Yet, the low reliability of this scale is accounted for by the SEM approach (i.e., higher measurement error results in higher standard errors for latent variables with lower reliability). Due to the non-normality of some items, the analysis used a robust maximum likelihood estimator providing robust standard errors and a scaled test statistic (Chou et al., 1991). The significance level used was $\alpha = .05$.

Correlations of all variables (as measured by their mean-scores) are given in Table 1 (because not all variables were normal-distributed, Spearman Rho correlation coefficients were also computed). Results for the hypothesis tests from the SEM analysis are given in Figure 2 (standardized parameters) and Table 2 (unstandardized parameters) and are interpreted in the text below.

Table 1.
Pearson and Spearman Rho Correlation Coefficients for all Variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	*Rel* (α)
(1) Acquisition by testing	—	.11	.31***	.47***	.22*	.21*	.13	.83
(2) Acquisition by monitoring	.04	—	-.11	-.05	-.08	.32***	.01	.44
(3) Acquisition by reading	.32***	-.12	—	.38***	.55***	.01	.10	.90
(4) Perceived strategy knowledge	.52***	-.05	.43***	—	.41***	.06	.20*	.94
(5) Technical system knowledge	.21*	-.06	.57***	.39***	—	-.15	.22*	.86
(6) Eco-driving motivation	.21*	.28**	.04	.10	-.15	—	.15	.81
(7) Fuel efficiency	.12	.00	.13	.15*	.17	.20*	—	.78

Notes. * $p < .05$; ** $p < .01$; *** $p < .001$; Pearson (above the diagonal) and Spearman Rho correlation coefficients (below the diagonal; for a comparison see de Winter, Gosling, & Potter, 2016); All *p*-values refer to two-sided significance tests. *Rel* (α), the last column, provides the Cronbach's α reliability coefficients for essentially tau-equivalent scales (Graham, 2006).

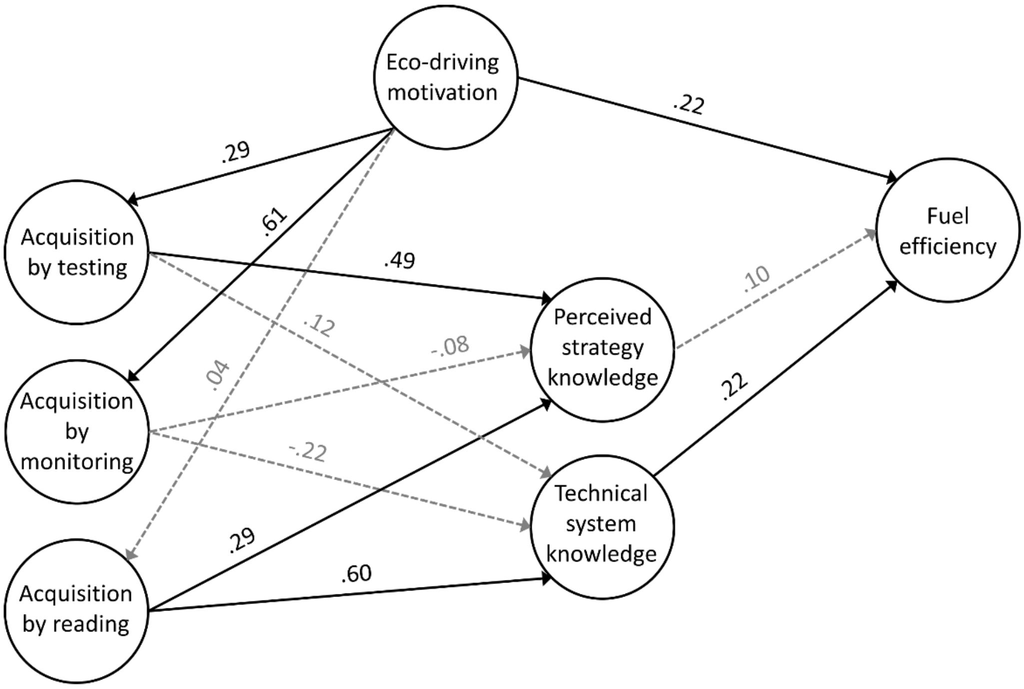

Figure 2. Depiction of relationships that received support from the SEM; Dark arrows indicate significant, grey arrows non-significant relationships.

5.1. Q1: Relationship of Perceived Strategy Knowledge to Fuel Efficiency

Overall, regarding the results for Q1, data indicated that perceived strategy knowledge was not significantly related to fuel efficiency. Although the correlation coefficients both indicated a small to medium and significant effect, when the effects of eco-driving motivation and technical system knowledge were also accounted for (both had small to medium and significant effects on fuel efficiency; see Table 1), the relationship between perceived strategy knowledge and fuel efficiency decreased and was not significant (see Table 2 and Figure 2). Consequently, H1 was rejected.

5.2. Q2: Relationship of Acquisition by Testing, Monitoring and Reading to Perceived Strategy Knowledge

To first get an indication of the relative importance of the three different acquisition types, boxplots and histograms were computed for the sub-scales (created by the mean of each pair of items) and are depicted in Figure 3.

Figure 3. Boxplots and histograms depicting the distributions of acquisition by testing, monitoring and reading (dashed lines represent means).

The figure indicates that most of the drivers agreed to having used reading and testing to acquire their strategy knowledge, whereas monitoring was reported to being used more sparsely and less intense. This is also reflected in the differences between the means of each variable: Acquisition by reading (M = 4.36; SD = 1.37) and acquisition by testing (M = 4.30; SD = 1.08) were most frequently used, followed by acquisition by monitoring (M = 3.60; SD = 0.97).

The results from the SEM (Table 2) indicate that acquisition by testing and acquisition by reading were significant predictors of perceived strategy knowledge. Consequently, H2.1 and H2.3 were supported: Acquisition by testing had large positive effect on perceived strategy knowledge and acquisition by reading had a medium positive effect on perceived strategy knowledge. In contrast, acquisition by monitoring was not related to perceived strategy knowledge (thus, H2.2 rejected).

Table 2.
Path Coefficients of the Hypothesized Relationships.

Hypo-thesis	Dependent variable	Independent variable	*B*	*95%-CI*	*Z*	*p*	R^2
		Perceived strategy knowledge	0.12	[-0.14; 0.37]	0.90	.183	
H1	Fuel efficiency	Technical system knowledge	0.24	[0.01; 0.48]	2.03	.021	.12
		Eco-driving motivation	0.22	[0.02; 0.42]	2.18	.015	
H2.1		Acquisition by testing	0.38	[0.21; 0.54]	4.53	<.001	
H2.2	Perceived strategy knowledge	Acquisition by monitoring	-0.10	[-0.38; 0.18]	-0.69	.754	.32
H2.3		Acquisition by reading	0.17	[0.06; 0.28]	2.92	.002	
H3.1		Acquisition by testing	0.10	[-0.07; 0.27]	1.16	.122	
H3.2	Technical system knowledge	Acquisition by monitoring	-0.32	[-0.69; 0.05]	-1.71	.957	.41
H3.3		Acquisition by reading	0.39	[0.27; 0.52]	6.29	<.001	
H4.1	Acquisition by testing	Eco-driving motivation	0.32	[0.04; 0.59]	2.28	.011	.09
H4.2	Acquisition by monitoring	Eco-driving motivation	0.39	[0.18; 0.59]	3.74	<.001	.36
H4.3	Acquisition by reading	Eco-driving motivation	0.07	[-0.22; 0.36]	0.46	.322	.00

Notes. *N* = 120. *P*-values for directional hypotheses are based on one-sided significance tests; *p*-values for non-directional hypotheses are based on two-sided significance tests. Additionally, the residual covariance between perceived strategy knowledge and technical system knowledge was included (*Cov* = 0.11; 95%-CI = [0.01; 0.23; *p* = .039). The whole model provided a reasonable fit for the data: robust RMSEA = 0.07; sample-size adjusted BIC(47) = 5117.779.

5.3. Q3: Relationship of Acquisition by Testing, Monitoring and Reading to Technical System Knowledge

Regarding the associations of technical system knowledge with the three acquisition types (see Table 2 and Figure 2), only H3.3 received support: Acquisition by reading was strongly and positively related to technical system knowledge but neither acquisition by testing nor acquisition by monitoring had a significantly positive effect. Consequently, H3.1 and H3.2 were rejected.

5.4. Q4: Relationship of Acquisition by Testing, Monitoring and Reading to Eco-Driving Motivation

Considering the relationships between the acquisition types and eco-driving motivation, acquisition by monitoring and acquisition by testing were related to eco-driving motivation. Consequently, H4.1 and H4.2 were supported (eco-driving motivation was medium and positively related to acquisition by testing as well as by monitoring) but H4.3 was rejected (eco-driving motivation was not significantly related to acquisition by reading).

5.5. Q5: Indirect and Total Effects of Acquisition Types on Fuel Efficiency

The indirect and total effects of all three acquisition types on fuel efficiency (mediated by technical system- and perceived strategy knowledge) were also analysed. As revealed by one-sided significance tests and bootstrapped standard errors (based on the Bollen-Stine procedure; Bollen and Stine, 1992), only acquisition by reading had a positive and small to medium indirect effect (B = 0.10; β = .14; z = 1.71; p = .043) via technical system knowledge on fuel efficiency. This indirect effect also accounts for the largest share of the positive total effect of acquisition by reading on fuel efficiency (B = 0.12; β = .16; z = 2.28; p = .012) which is only slightly increased due to the relationship via perceived strategy knowledge. These results indicate that drivers who acquire eco-driving knowledge by reading benefit from higher fuel efficiency—particularly due to higher technical system knowledge.

6 DISCUSSION

6.1. Summary of Results

The objective of the present research was to examine HEV drivers acquisition of perceived strategy knowledge and technical system knowledge by testing, monitoring and reading as well as the relationship between perceived strategy knowledge and fuel efficiency. Perceived strategy knowledge was not significantly related to fuel efficiency in a model with technical system knowledge and eco-driving motivation as further predictors (Q1). In terms of acquisition, perceived strategy knowledge was related to the systematic testing of strategies and reading (Q2). In contrast, technical system knowledge, a known positive predictor of fuel efficiency, was solely and strongly related to acquisition by reading (Q3). Eco-driving motivation was related to acquisition by testing as well as monitoring system feedback (Q4). Finally, acquiring eco-driving knowledge through reading, which was reported to having been the most frequently used acquisition strategy, had a positive indirect and total effect (mediated primarily by technical system knowledge) on fuel efficiency (Q5).

6.2. Theoretical Implications

The present research contributes to the framework and understanding of eco-driving in HEVs from various perspectives. First, the results indicate that perceived strategy knowledge does not (at most: only weakly) relate to fuel efficiency when the influences of technical system knowledge and eco-driving motivation are controlled. In contrast, technical system knowledge was significantly related to fuel efficiency. This means that knowing *why* eco-driving strategies are efficient has a superior effect on fuel efficiency than believing to know *what* is energy efficient. For the control-theoretic model introduced in the Background section, this underlines the importance of technical system knowledge for eco-driving success and supports its central role in a framework of eco-driving.

Second, building upon these results, an important implication is that technical system knowledge, as the more important factor regarding eco-driving success, was exclusively and strongly related to acquisition by reading. A possible reason for this might be that the rather complex HEV powertrain (McIlroy et al., 2013) requires rather specific knowledge that cannot be gained in interaction with the system but only by external sources such as websites or manuals. In comparison, acquiring knowledge by interacting with the vehicle (testing and monitoring) was more related to strategy knowledge. From the perspective of control theory, one possible explanation for this could be that drivers with higher technical system knowledge base their eco-driving behaviour more on target states that are deduced from this knowledge and thus *evaluated* as efficient considering the system states and energy dynamics. In contrast, drivers who acquired their knowledge more while driving (i.e., testing and monitoring) can be hypothesized to use target states that they *perceive* energy efficient based on the feedback that they can derive from the vehicle. Yet, because of the HEV driving in rapidly varying driving situations, eco-driving knowledge acquisition in the vehicle might be more vulnerable to confounding factors and, thus, could lead to false conceptualisations and rather inefficient conclusions about what is energy efficient (or not).

Third, acquiring knowledge in interaction with the vehicle (testing and monitoring) was used by drivers with higher, rather than lower, eco-driving motivation. This result sheds further light on the special role eco-driving motivation plays for HEV drivers eco-driving behaviour: Previous research has already indicated that highly motivated drivers sometimes use less efficient strategies and tend to base their energy efficiency conceptualisations (part of the perceived strategy knowledge base) more on system feedback than less motivated drivers (Arend and Franke, 2017; Franke et al., 2016), which impairs their eco-driving success. The present study broadens this picture with the finding that more motivated drivers used rather less efficient knowledge acquisition strategies. This emphasizes that eco-driving support systems must also be designed to facilitate eco-driving for those drivers that are highly-motivated but have rather low eco-driving success (partly due to their lower technical system knowledge).

Finally, regarding the different acquisition types, results showed that most HEV drivers acquire their knowledge through systematic testing and reading. For the acquisition by reading, this is a promising finding because reading comprises the potential of reduced fuel savings (based on the positive relationship to technical system knowledge; Q5). Monitoring of system feedback provided to HEV drivers was more sparsely used, compared to reading and testing. This emphasizes the need of improved in-vehicle eco-driving support systems which allow the acquisition of efficient eco-driving strategies as well as technical system knowledge. Suggestions on this are given in the next section.

6.3. Practical Implications

Summarizing the theoretical implications, it is evident that the acquisition of technical system knowledge is crucial for HEV eco-driving success but is currently also only promoted by information given in manuals, on websites or in books (acquisition by reading). Consequently, system designers should provide drivers with the means that support the acquisition of more relevant and adequate eco-driving knowledge (i.e., the formation of more correct mental models of the system; Pampel et al., 2015; Revell and Stanton, 2012). Obviously, from a usability perspective, it is not the best solution to provide drivers with the necessary information via books or websites (i.e., learning contexts separated from driving). It would facilitate the learning considerably if eco-driving support systems would convey this eco-driving knowledge whilst driving (indeed, drivers who are not motivated to spend time for knowledge acquisition beyond their usual trips could also be reached). Thus, such systems should be designed to encourage the acquisition of technical system knowledge and provide drivers with the means to deduce adequate target system states for their eco-driving strategies. Some opportunities for such support systems are as follows.

Because monitoring was particularly frequently used by motivated eco-drivers, a first approach towards enhanced eco-driving support systems could be to adapt the system feedback. Eco-driving support provided via different modalities, such as visual (Birrell and Fowkes, 2014; Kircher et al., 2014), haptic (McIlroy et al., 2017; Staubach et al., 2014) or auditory feedback (Hibberd et al., 2015;

Jamson et al., 2015a) has been subject to investigation. Visual information could be designed to improve the drivers understanding of the current system state (e.g., how energy efficient different states of the powertrain are and why). Additionally, haptic information could be used to indicate the system states most energy efficient (McIlroy and Stanton, 2017; Perelló et al., 2017). Such an approach would promote the acquisition of technical system knowledge via visual information as well as provide drivers with the necessary driving skills (part of perceived strategy knowledge) by recommending the optimal target system states (in the terms of the control-theoretic model) via haptic information.

In this respect, a tutorial mode that imparts technical system knowledge to the drivers for a certain period might be another worthwhile solution. This mode could also include more specific information via the visual system feedback (as outlined above), haptic information and, additionally, auditory information (such as, explanations how the powertrain works during acceleration, deceleration, etc.). System design approaches such as gamification (Deterding et al., 2011) could be used to motivate the acquisition of the required eco-driving knowledge. In the cases of advanced eco-driving feedback as well as tutorial modes, those systems must be designed to minimise the potential distraction such eco-driving support systems provide (Ahlstrom and Kircher, 2017; Young et al., 2011) because of the potential conflict over cognitive and visual resources required for driving (Birrell et al., 2017; Parnell et al, 2017). For example, more specific information in tutorials may only be given when the vehicle is stationary at a red traffic-light.

The type of information that should be given to drivers to facilitate technical system knowledge and fuel-saving driving behaviours can be deduced from previous research. In general, it seems to be important that enough understanding of the energy conversions inherent in the HEV system is ensured (Arend and Franke, 2017; Franke et al., 2016). Furthermore, a correct knowledge of the functioning of specific driving modes (such as the B-mode which activates engine braking) should be supported to avoid the (mis)use of driving modes based on false conceptualisations that these modes are particularly energy-efficient (Franke et al., 2016). With that, further general false beliefs, for example concerning the utilization of electric energy, could be specifically targeted and clarified by such a tutorial mode.

6.4. Limitations

When interpreting the result of the present research some limitations should be kept in mind. Firstly, the perceived strategy knowledge assessed here refers to a subjective assessment of knowledge (i.e., drivers' subjective perception of knowing what yields higher fuel efficiency). Hence, the results in the present research only apply to this subjective strategy knowledge. There have been alternative approaches to assess eco-driving strategy knowledge in a more objective way, such as the number of eco-driving strategies drivers report (McIlroy & Stanton, 2017). Future research should also consider the relationship between the subjective and objective eco-driving knowledge.

Furthermore, a subjective approach was also used for the assessment of technical system knowledge. Indeed, it could have been more appropriate to use an objective assessment approach for this knowledge component. Yet, constructing a valid knowledge test that assesses different levels of knowledge equally reliably requires a different approach and large sample sizes (e.g., Edelen and Reeve, 2007). Therefore, we relied on a scale which has been validated and applied in various research projects (e.g. Franke et al., 2015; Neumann et al., 2015) and can thus be assumed to be a reasonable indicator of driver's actual technical system knowledge. Nevertheless, future research would benefit from an alternative approach towards the assessment of objective technical system knowledge.

Finally, the scale assessing the acquisition of eco-driving knowledge by monitoring system feedback had very low reliability in the present study. Although this low reliability is accounted for by the SEM approach, future research should focus on developing a more reliable scale in order to assess the role of this acquisition type with higher statistical power. One possibility for this could be to develop a scale with more items, which should increase reliability (Peter, 1979).

7 CONCLUSION

The objective of the present research was to advance understanding of HEV drivers' acquisition of perceived strategy knowledge and technical system knowledge and the relationships of both to fuel efficiency. Perceived strategy knowledge, mostly acquired in interaction with the HEV, was not related to higher eco-driving success. In contrast, technical system knowledge was shown to be an important factor for the energy efficiency achieved. This knowledge type was acquired by reading information in books, manuals or on websites. These results implicate that perceiving to know what is energy efficient is less important for HEV eco-driving success than knowing why it is energy efficient (or not). Consequently, future research should identify ways that allow the easier formation of technical system knowledge based on advanced eco-driving support systems.

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10 APPENDIX

10.1. Appendix A

Appendix A.
Translated Items of all Scales Used in the Present Research

Scale Label	Item label	Item Text
		Items:
Strategy knowledge	**sk1**	I know exactly what to do to drive energy efficient.
	sk2	I know exactly how to handle the controls (accelerator pedal, gearstick, EV-button, adaptive cruise control, …) to drive maximum energy efficient.
	sk3	I do not know very much about the fuel efficient control of my vehicle.
		Items:
Technical system knowledge	**tk1**	I am familiar with the propulsion technology of hybrid cars (e.g., types and functionality of electric motors).
	tk2	I am familiar with concepts like energy density and energy conversion efficiency.
	tk3	I have an idea about how regenerative braking technically works.
		Items:
Eco-driving motivation	**m1**	I am always striving to drive fuel efficiently.
	m2	I often try to drive as fuel efficiently as possible.
Fuel efficiency		*Item for estimated fuel consumption*: What was the average fuel consumption you achieved with your currently most-used HEV in the previous summertime (beginning of April to end of September 2015)? *Item for estimated fuel consumption on an urban route*: Description of the driving situation (the same for all dimensions): – You are alone on the road with your HEV. – The weather is sunny and calm/windless with 20°C. – The car (the engine/motor) is already warm. – You are familiar with the route. – The terrain is relatively flat. – There is little traffic on the route. You are on a longer route (> 20km) in an urban area (main- and byroads, with speed limits of 30, 50 and 70 km/h, traffic lights, crossings). What would be your typical fuel consumption under these conditions? *Item for estimated fuel consumption on a rural route*: (driving situation is the same as before, except for the last point, which was changed accordingly): – You are on a longer route (> 20km) in a rural area with country roads and small villages. What would be your typical fuel consumption under these conditions?
		Items:
Acquisition by testing	**acq1**	I have attempted to figure out which driving behaviour yields the lowest fuel consumption by systematic testing of different strategies/influencing factors.

	acq2	I have intensively studied the factors which yield a high/low fuel consumption.
Acquisition by monitoring		*Items*:
	acq3	I totally relied on the system feedback in the vehicle when learning eco-driving strategies.
	acq4	The system feedback in the vehicle educated me when learning eco-driving strategies.
Acquisition by reading		*Items*:
	acq5	I have intensively read up on the topic saving fuel in HEVs (e.g., manuals, websites, books, …).
	acq6	I have intensively read up on the technical background of HEVs' energy efficiency (e.g., manuals, websites, books, …).

Figure 1

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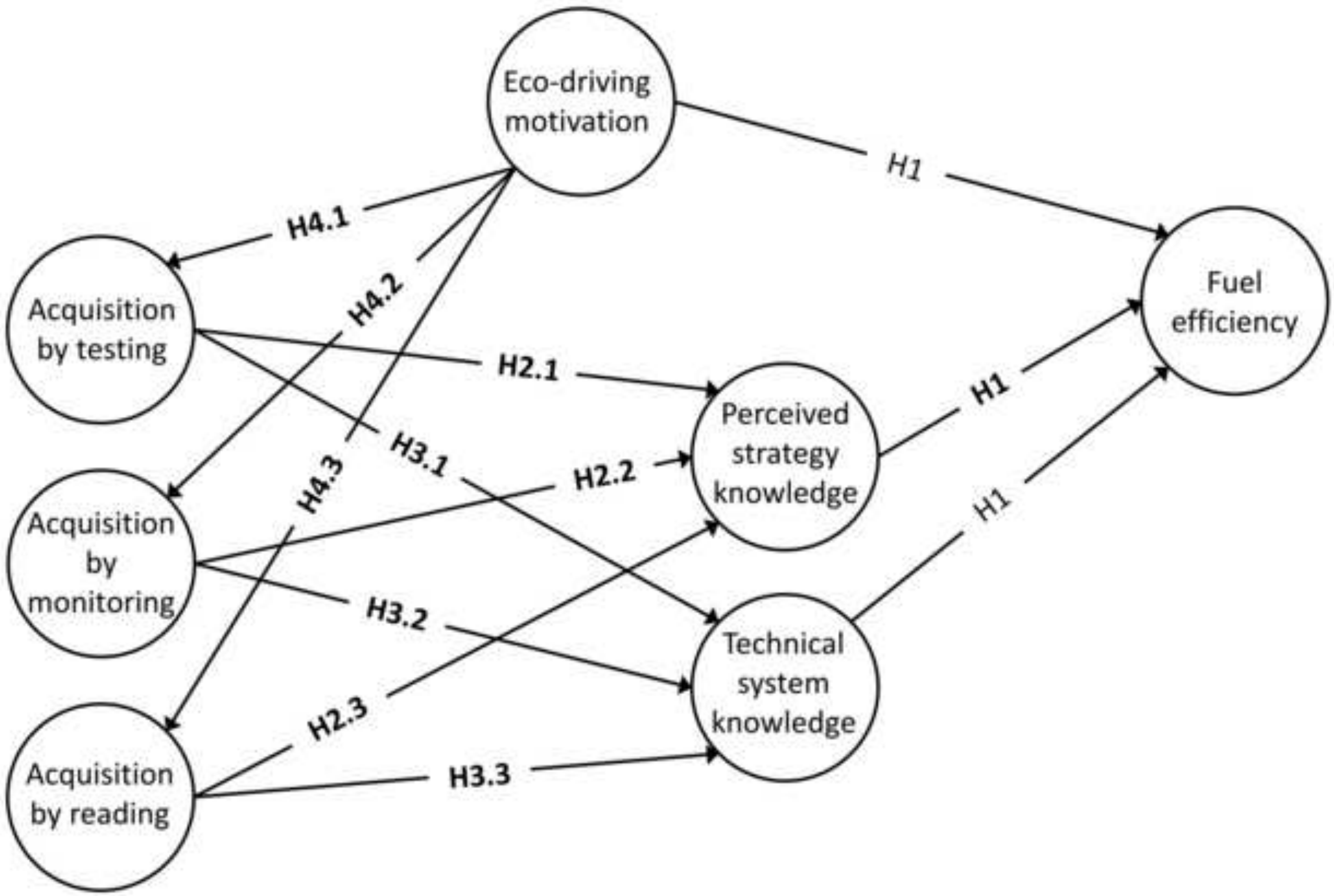

Figure 2
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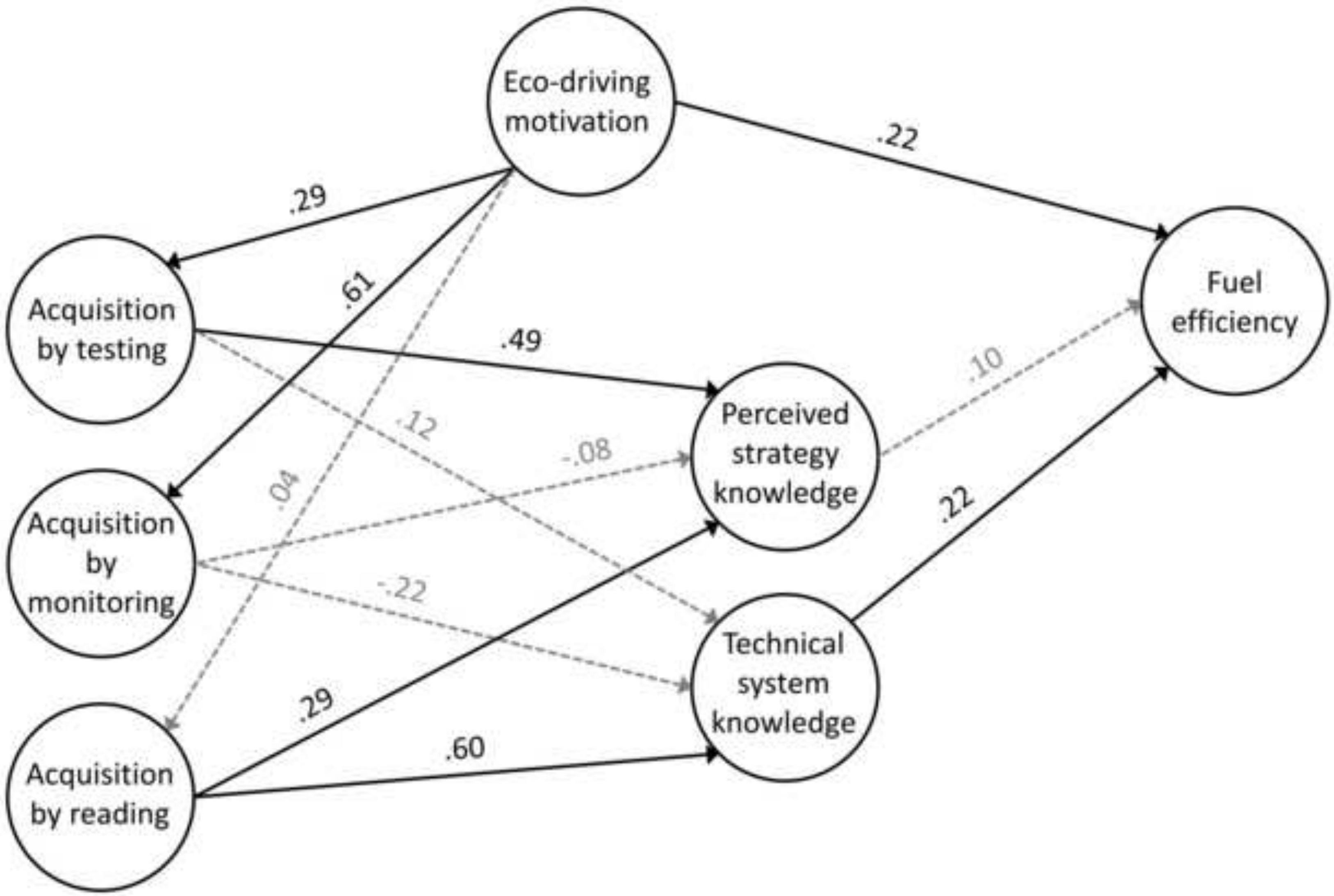

Figure 3
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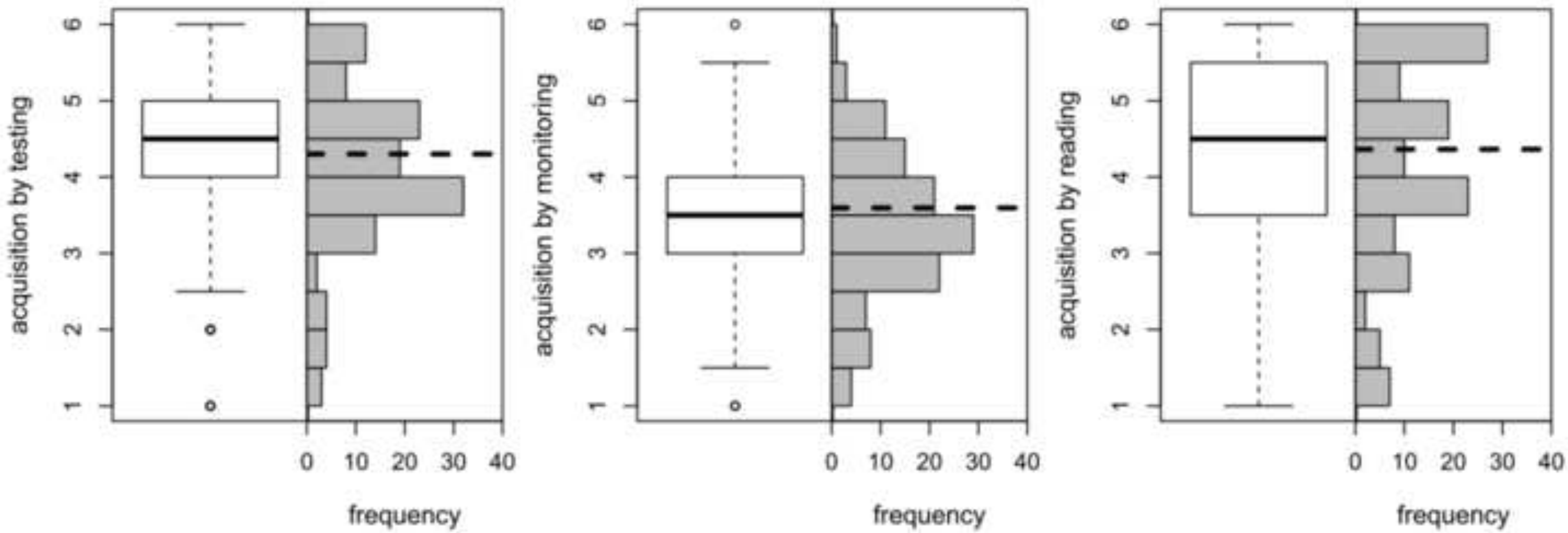

Table 1

Table 1.
Pearson and Spearman Rho Correlation Coefficients for all Variables

	Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	*Rel* (α)
(1)	Acquisition by testing	—	.11	.31***	.47***	.22*	.21*	.13	.83
(2)	Acquisition by monitoring	.04	—	-.11	-.05	-.08	.32***	.01	.44
(3)	Acquisition by reading	.32***	-.12	—	.38***	.55***	.01	.10	.90
(4)	Perceived strategy knowledge	.52***	-.05	.43***	—	.41***	.06	.20*	.94
(5)	Technical system knowledge	.21*	-.06	.57***	.39***	—	-.15	.22*	.86
(6)	Eco-driving motivation	.21*	.28**	.04	.10	-.15	—	.15	.81
(7)	Fuel efficiency	.12	.00	.13	.15*	.17	.20*	—	.78

Notes. * $p < .05$; ** $p < .01$; *** $p < .001$; Pearson (above the diagonal) and Spearman Rho correlation coefficients (below the diagonal; for a comparison see de Winter, Gosling, & Potter, 2016); All *p*-values refer to two-sided significance tests. *Rel* (α), the last column, provides the Cronbach's α reliability coefficients for essentially tau-equivalent scales (Graham, 2006).

Table 2

Table 2.
Path Coefficients of the Hypothesized Relationships.

Hypo-thesis	Dependent variable	Independent variable	*B*	*95%-CI*	*z*	*p*	R^2
		Perceived strategy knowledge	0.12	[-0.14; 0.37]	0.90	.183	
H1	Fuel efficiency	Technical system knowledge	0.24	[0.01; 0.48]	2.03	.021	.12
		Eco-driving motivation	0.22	[0.02; 0.42]	2.18	.015	
H2.1		Acquisition by testing	0.38	[0.21; 0.54]	4.53	<.001	
H2.2	Perceived strategy knowledge	Acquisition by monitoring	-0.10	[-0.38; 0.18]	-0.69	.754	.32
H2.3		Acquisition by reading	0.17	[0.06; 0.28]	2.92	.002	
H3.1		Acquisition by testing	0.10	[-0.07; 0.27]	1.16	.122	
H3.2	Technical system knowledge	Acquisition by monitoring	-0.32	[-0.69; 0.05]	-1.71	.957	.41
H3.3		Acquisition by reading	0.39	[0.27; 0.52]	6.29	<.001	
H4.1	Acquisition by testing	Eco-driving motivation	0.32	[0.04; 0.59]	2.28	.011	.09
H4.2	Acquisition by monitoring	Eco-driving motivation	0.39	[0.18; 0.59]	3.74	<.001	.36
H4.3	Acquisition by reading	Eco-driving motivation	0.07	[-0.22; 0.36]	0.46	.322	.00

Notes. *N* = 120. *P*-values for directional hypotheses are based on one-sided significance tests; *p*-values for non-directional hypotheses are based on two-sided significance tests. Additionally, the residual covariance between perceived strategy knowledge and technical system knowledge was included (*Cov* = 0.11; 95%-CI = [0.01; 0.23]; *p* = .039). The whole model provided a reasonable fit for the data: robust RMSEA = 0.07; sample-size adjusted BIC(47) = 5117.779.