A Review of Research on Driving Styles and Road Safety

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Objective: The aim of this study was to outline a conceptual framework for understanding driving style and, on this basis, review the state-of-the-art research on driving styles in relation to road safety.

Background: Previous research has indicated a relationship between the driving styles adopted by drivers and their crash involvement. However, a comprehensive literature review of driving style research is lacking.

Method: A systematic literature search was conducted, including empirical, theoretical, and methodological research, on driving styles related to road safety.

Results: A conceptual framework was proposed whereby driving styles are viewed in terms of driving habits established as a result of individual dispositions as well as social norms and cultural values. Moreover, a general scheme for categorizing and operationalizing driving styles was suggested. On this basis, existing literature on driving styles and indicators was reviewed. Links between driving styles and road safety were identified and individual and sociocultural factors influencing driving style were reviewed.

Conclusion: Existing studies have addressed a wide variety of driving styles, and there is an acute need for a unifying conceptual framework in order to synthesize these results and make useful generalizations. There is a considerable potential for increasing road safety by means of behavior modification. Naturalistic driving observations represent particularly promising approaches to future research on driving styles.

Application: Knowledge about driving styles can be applied in programs for modifying driver behavior and in the context of usage-based insurance. It may also be used as a means for driver identification and for the development of driver assistance systems.

Keywords: driver profiling, driving pattern, driving habit, driver behavior

INTRODUCTION

The concept of individual differences between drivers regarding crash involvement probability, and possible explanations in terms of behavior and background factors, dates back to the old ideas of "accident proneness" as a general characteristic predisposing a person for involvement in all types of accidents. This idea first appeared as an explanation for industrial accidents but was later also applied to road accident involvement (for an overview and references regarding accident proneness, see Shinar, 2007, pp. 342-343).

Although accident proneness as a general predisposition for involvement in all types of accidents has been discarded (Shinar, 2007), there seems to be clear evidence from road safety research that drivers differ in crash involvement risk and that these differences tend to be relatively stable over time (see. e.g., Häkkinen, 1958).

The earliest research on individual differences in crash risk focused on driver background factors (e.g., personality, socioeconomic background). For example, Tillmann and Hobbs (1949) carried out detailed interviews with crash-involved and crash-free taxi drivers and found significant differences in their backgrounds. Part of the interviews with taxi drivers took place during taxi trips, providing observational data for qualitative descriptions of "driving habits." The driving habits of taxi drivers with a high accident frequency were described as follows:

> As a group they were easily distracted while driving. They tended to be readily annoyed at other motorists on the road, often criticising their own driving mistakes in others. Horn honking and racing other cars away from a stop light were their specialties. (Tillmann & Hobbs, 1949, p. 325)

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The taxi drivers with low accident frequency, on the other hand, were described in the following way:

> These men were serious when driving and often refused to talk. They tended to be courteous to other drivers on the road and stated that they were conscious of the fact that the other driver might do the wrong thing. They appreciated the possible limitations of their vehicle. (Tillmann & Hobbs, 1949, p. 326)

In a second study, they compared a group of 96 crash-involved drivers from the general population with a control group of 100 crash-free drivers and found clearly significant differences in registered previous contacts with juvenile and adult courts, public health agencies, and social service agencies handling family-related problems. One of their conclusions was the well-known saying that "a man drives as he lives" (Tillman & Hobbes, 1949, p. 329).

Apart from such rather cursory observations, the early studies of individual differences in crash involvement did not include actual measurements of driving behavior, but it was more an implicit assumption that the relationship between social background and personality on the one hand and crash involvement on the other was mediated by differences in ways of driving.

One of the earliest quantitative studies of individual differences including behavior measurements was done by Weiss and Lauer (1930). They made a list of 44 driving behaviors supposed to be relevant indicators of the quality of driving, for example, "application of brakes," "coasting downhill," "use of rearview mirror," "fail to signal," and so on. In-vehicle observers then rated individual drivers on a scale from 1 to 5 on each behavior item. However, these authors did not present any results relating the behavior scores to more objective safety indicators, like crash involvement. In the 1950s, some studies correlated rating scales and driving habit checklists with accident involvement (see Häkkinen, 1958, p. 77). There was also a series of studies of driving habits by Lewis (1953, 1956), using in-vehicle camera observations of a small group of drivers. The results suggested that "safe drivers drive more constantly in the same manner when the same driving situations are repeated" (Häkkinen, 1958, p. 78).

The seven decades that have passed since those first attempts of systematic and scientific observations of differences in driving habits (or driving styles) have witnessed a tremendous development in this field of research. Although it is generally assumed that driving styles are related to crash risk, there are still several unresolved issues regarding the details of this relationship and how safe versus unsafe driving styles should best be modeled and measured. However, perhaps most importantly, there is still a lack of a common underlying conceptual framework to guide this research and clearly distinguish the concept of driving style from other constructs, such as driver state, driver condition, and driver behavior in general.

Research on driving styles has used both self-report methods and observation of actual behavior. Self-report instruments have mostly been developed with the explicit aim of measuring driving styles, whereas direct observation of driving styles uses more or less the same methods as in research on driving behavior in general. Table 1 shows an overview with examples of both self-report and behavior observation/recording methods. It should be noted that several of the studies reviewed here have used a combination of self-report and observation methods.

In this paper, we first discuss key terms and definitions commonly used in this research area and suggest a general definition of driving style. We then outline a framework for conceptualizing driving style and a scheme for categorization and operationalization in terms of global and specific driving styles. On this basis, we review the literature on (a) global and specific driving styles, (b) the relation between self-reported and observational measures of driving styles, (c) the association between driving style and road safety, (d) background factors that influence driving styles, and (e) potential applications of driving style research, in particular, techniques for modifying driving style. We conclude with a summary of the main findings and some suggestions for future directions of driving style research.

TABLE 1: Data Collection Methods to Study Driving Styles

Method	Sample References
Self-report instruments	
Driving Style Questionnaire (DSQ)[a]	West, French, & Elander, 1990; French, West, Elander, & Wilding, 1993
Driving Style Questionnaire[a]	Ishibashi, Okuwa, Doi, & Akamatsu, 2007
Driving Behaviour Questionnaire (DBQ)	Reason, Manstead, Stradling, Baxter, & Campbell, 1990; Parker, Reason, Manstead, & Stradling, 1995
Multidimensional Driving Style Inventory (MDSI)	Taubman-Ben-Ari, Mikulincer, & Gillath, 2004
Driver Vengeance Questionnaire	Wiesenthal, Hennessy, & Gibson, 2000
Driving Anger Scale (DAS)	Deffenbacher, Oetting, & Lynch, 1994
Driving Anger Expression Inventory (DAI)	Deffenbacher, Lynch, Oetting, & Swaim, 2002
Driver Aggression Indicators Scale (DAIS)	Sümer, Ozkan, & Lajunen, 2006
Propensity Towards Angry Driving (PAD)	Dahlen & Ragan, 2004
Dula Dangerous Driving Index (DDDI)	Dula & Ballard, 2003
Driving Behaviour Inventory (DBI)[b]	Gulian, Matthews, Glendon, Davies, & Debney, 1989
Behavior recording	
Observation by in-vehicle observer	Tillman & Hobbs, 1949; West, French, Kemp, & Elander, 1993; Bukasa & Risser, 1985; Amado, Arikan, Kaca, Koyuncu, & Turkan, 2014
Site-based traffic observation	Keskinen, Ota, & Katila, 1998; Aronsson, 2006
Simulator study	Ungoren & Peng, 2005; Desai & Haque, 2006; Yan, Radwan, & Guo, 2007; de Waard, Dijksterhuis, & Brookhuis, 2009; Farah, Bekhor, Polus, & Toledo, 2009; Richer & Bergeron, 2009; Cho, Nam, & Lee, 2006; Xiong, Boyle, Moeckli, Dow, & Brown, 2012; Chen, Fang, & Tien, 2013
Controlled field study with instrumented vehicle	Miyajima et al., 2007; Takeda et al., 2011; Paefgen, Kehr, Zhai, & Michahelles, 2012
Naturalistic driving observation	Paefgen et al., 2012; Johnson & Trivedi, 2011; Eren, Makinist, Akin, & Yilmaz, 2012; Hong, Margines, & Dey, 2014; af Wåhlberg, 2006; Bagdadi & Várhelyi, 2011; Reagan, McClafferty, Berlin, & Hankey, 2013; Knipling et al., 2004

[a]There are two quite different instruments with the name Driving Style Questionnaire. We will use the acronym DSQ only for the West et al. (1990) questionnaire.
[b]The DBI was developed in order to study *driver stress*. It is listed here because it includes some behavioral items closely related to driving style, such as "When irritated I drive aggressively," and because it is used extensively in research on driving styles.

INCLUSION CRITERIA FOR REVIEW

Candidate material was gathered by a systematic search on IEEE Xplore and ISI Web of Science, with search terms *driving style* and *safety*; this procedure gave about 90 hits. This set was supplemented by literature previously known by the authors, as well as from informal search on Google Scholar, yielding a total set

of about 160 literature items (articles, books, reports).

Literature items were considered relevant if they focused on either (a) driving styles related to road safety, (b) driving behavior relevant to research on driving style and road safety, (c) methodologies to study and/or infer driving styles, or (d) factors shown or assumed to influence driving styles. A further selection of papers to consider for review was made based on a preliminary definition of driving style as pertaining to differences in driving behavior between drivers or groups of drivers (the issue of defining driving style will be further discussed later), such that research focusing on differences between driving situations rather than between drivers was excluded. Only literature explicitly addressing some indicator(s) or measure(s) of driving style, or some specific example of a driving style, was included in this review; hence literature mentioning driving style as an unspecified concept was excluded. On the basis of these criteria, a total of about 100 literature items related to driving styles were reviewed. About one half of the items had the words *driving style* in the title or abstract.

To make this review manageable, the literature on driving styles or driving behaviors not related to road safety (e.g., related to fuel economy and environmentally friendly driving) are not covered here but are addressed in, for example, Ericsson (2000); Savaresi, Manzoni, Corti, and De Luca (2010); and Rafael, Sanchez, Mucino, Cervantes, and Lozano (2006).

DEFINING DRIVING STYLE

Definitions of driving style found in the reviewed literature are given in Table 2. The definition by Lajunen and Özkan (2011) is very much in accordance with the definition by Elander, West, and French (1993). The definition by Murphey, Milton, and Kiliaris (2009) differs considerably from most other definitions, in being almost equivalent to driving behavior in general, and thus this definition is probably too general to be very useful. Other definitions tend to emphasize decision making (Deery, 1999) and ways of thinking (Ishibashi, Okuwa, Doi, & Akamatsu, 2007) rather than observable behavior.

Despite the differences, there seem to be some aspects that most definitions have in common, which we can summarize in the following three conditions defining the concept of driving style. First, driving styles differ across individuals or between groups of individuals. Second, a driving style is a habitual way of driving, which means that it represents a relatively stable aspect of driving behavior. Third, most definitions in Table 2 imply that driving styles reflect conscious choices made by the driver. We will endorse the first two conditions. However, we will question the usefulness of implying that the driver deliberately choses his or her driving style. Thus, we include both consciously chosen ways of driving and subconscious, automatized behavior in our definition, as long as the behavior is habitual and relatively permanent. In Lajunen and Özkan's (2011) definition, driving *skills* and driving *style* represent two complementary and independent pathways to crash risk. We will suggest a link from driving skills to driving style, implying that a person's driving style is partly a function of his or her driving skills, in addition to the conscious choices made during driving. Some definitions include the additional criterion that driving styles "become established over a period of years" (Elander et al., 1993) or "have developed over time" (Deery, 1999). We do not think this is a necessary criterion, since it seems to exclude the existence of driving styles among novice drivers.

Here we make an attempt to capture most of the common elements in previous definitions in an effort to have a clear and applicable definition for future work in this field and also to distinguish between driving styles and the wider concept of driving behavior. Therefore, we define a driving style as a "habitual way of driving, which is characteristic for a driver or a group of drivers." By "habitual way of driving," we mean driving behavior that tends to occur in a consistent way across driving occasions for a given driver and that may include both automatized skills and more consciously controlled behavior. The concept of a driving habit is further elaborated in the following section. *Driving* here refers broadly to all behaviors performed by the driver related to the goal of traveling from Point A to Point B, including basic vehicle control,

TABLE 2: Existing Definitions of Driving Style

Definition	Reference
"Driving style concerns individual driving habits—that is, the way a driver chooses to drive"	Lajunen & Özkan, 2011
"Driving style concerns the way individuals choose to drive, or driving habits that have become established over a period of years"	Elander, West, & French, 1993
"An attitude, orientation and a way of thinking for daily driving"	Ishibashi, Okuwa, Doi, & Akamatsu, 2007
"Driving style is concerned with decision making aspects of driving, that is, the manner in which people choose to drive or driving habits that have developed over time"	Deery, 1999
"Driving style is defined as a set of activities and steps that an operator uses when driving an engine powered vehicle, according to his personal judgment, experience and skills"	Rafael, Sanchez, Mucino, Cervantes, & Lozano, 2006
"Driving style is the way in which a driver chooses to drive and is governed by a combination of social, neurobehavioral, and biological mechanisms"	de Groot, Centeno Ricote, & de Winter, 2012
"Driving style is described as a relatively stable characteristic of the driver, which typifies his/her personal way of driving, the way he/she chooses to drive"	Saad, 2004
"Dynamic behaviour of a driver on the road"	Murphey, Milton, & Kiliaris, 2009
"One's preferred way of driving that, over time, develops into driving habits"	Kleisen, 2011

tactical decisions, and strategic decisions related, for example, to route choice and seat belt use. *Driving habit* is commonly used interchangeably with *driving style* (e.g., in the first two definitions mentioned earlier). It should be noted, though, that Kleisen (2011) distinguishes between driving style and driving habit and defines driving style as "one's preferred way of driving that, over time, develops into driving habits" (p. 156). As pointed out earlier, our view is that both consciously preferred action and automatized habits may be defined as driving styles. Furthermore, our definition entails the possibility that an individual driver may have a repertoire of driving styles applied under different conditions, for example, in a specific driving environment.

It is necessary to clarify the distinction between driving style and driving behavior in general. The concept of driving behavior includes all actions (both overt acts and covert or mental operations) a driver performs during driving. Driving styles are subcategories of driving behavior, satisfying the criteria of varying systematically between individual drivers or groups of drivers and also being habitual, as implied by the definition earlier. Driving behavior varies systematically also across different road, traffic, and driving conditions, such as traffic density, road geometry, weather, light conditions, and so on. Drivers may show different patterns of behavior in different conditions. We have chosen to exclude behavior patterns that are determined exclusively by the driving context from our definition of driving style.

A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING DRIVING STYLE

As we have shown in the previous section, the concept of driving style has been hard to pin down, and the term has been used in a variety of different meanings. Thus, in order to structure the present review, there is a need for a more precise conceptualization of the driving

style construct. We have not found any research literature explicitly discussing habit formation as applied to the development of driving styles. Although it is beyond the scope of this review to present a complete theory or model for the development of driving styles, we will present a tentative framework here. The framework is based mainly on the concept of reinforcement and the assumption that the reinforcement conditions during driving are constituted by a wide variety of individual, social, cultural, environmental, and technological factors.

This section thus expands on the general definition we proposed with the aim to outline a tentative framework for understanding driving style. In the previous section, we proposed to define driving style as a "habitual way of driving, which is characteristic for a driver or a group of drivers." Thus, the core idea in this definition is the link between driving style and habit. In order to make this idea explicit, the concept of a driving habit needs to be further elaborated.

The general idea proposed here is that driving habits are formed partly as a result of individual driver characteristics, partly by social and cultural values, and partly by existing technology. *Individual characteristics* include driving skills as well as dispositions toward certain behaviors related to personality characteristics (e.g., sensation seeking, risk taking) that could be partly biologically determined. *Sociocultural values* refers to the norms regarding preferred or acceptable driving behavior that prevail in the driver's local social context (e.g., family, friends, and employer) as well as on the national/regional level. *Technological factors* include, for example, the way the vehicle is constructed (e.g., the steering and braking dynamics) as well as onboard systems that alert the driver of potential hazards and/or automate part of the driving task.

We further suggest that certain driving behaviors develop into habits by a process of *reinforcement*. There may be different reasons why a certain driving behavior occurs in the first place. On the one hand, it may be related to certain *motives*, including the general motive to arrive at the destination as well as more specific *extra motives* (Näätänen & Summala, 1976), which may be more or less related to the goal of accomplishing the trip. These extra motives may include expediency (e.g., arrive at the destination as fast as possible), aggression (e.g., a desire for retaliation if offended by another road user), compliance to behavioral norms (e.g., keeping up with the traffic pace), proving oneself to peers, or seeking the thrill of speeding. Extra motives may also include the desire to perform secondary, non-driving-related tasks, such as texting or talking on the cell phone while driving. As suggested by Näätänen and Summala (1976), such *excitatory motives* are balanced by *inhibitory motives*, which serve to hold back certain behaviors associated with too-high costs, related, for example, to the perceived risk of crashing, receiving a speeding ticket, or violating socially accepted norms.

Alternatively, the driver may engage in some behavior more or less by coincidence, without necessarily making a conscious decision. Such behaviors may be the result of intuitive conceptions of how to behave while driving, and they may also be influenced by the driver's skills and knowledge. In addition, behavior selection is influenced by technological factors. For example, engagement of an adaptive cruise control function may be regarded a behavior in itself, which has a strong impact on longitudinal vehicle control. Furthermore, behavior selection is strongly determined by the current driving situation, which creates opportunities or constraints for action. For example, a driver strongly motivated to send a text message may be more inclined to do so while driving on a sparsely trafficked motorway than in busy city driving; a desire to overtake may be put into action only if the driver judges that overtaking is possible given the present traffic situation. Irrespective of its origin, we suggest that a behavior may become reinforced and develop into a habit if it consistently results in positive outcomes. The term *driving style* thus refers to those driver behaviors that have developed into driving habits and hence recur reliably within and between trips. The proposed framework is summarized in Figure 1.

Finally, it should be noted that driving styles may belong to all levels in the well-known hierarchical, trilevel model of driving behavior, distinguishing between behavior at the *strategic, tactical*, and *operational* levels (Michon, 1985).

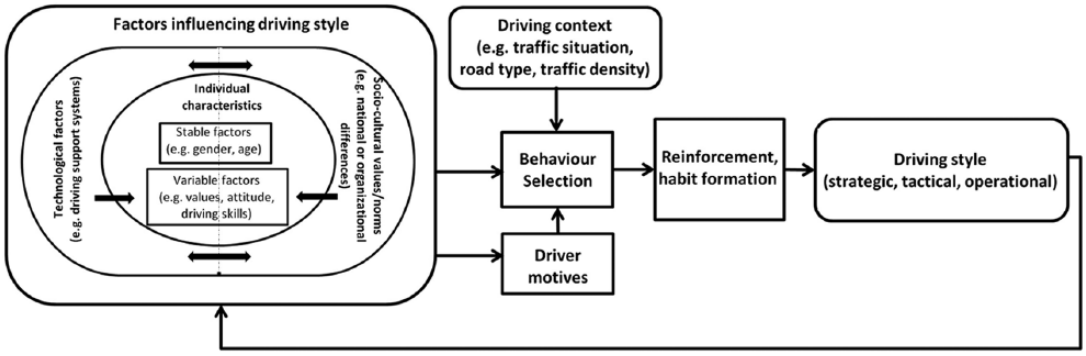

Figure 1. A tentative model of the establishment of driving style in terms of a process of habit formation.

Driving styles at the operational level include steering or acceleration habits. Driving styles at the tactical level include, for example, the habitual choice of speed and headway, and examples of driving styles at the strategic level include habitual route choice and seat belt use. A similar trilevel classification, with particular reference to driver information needs, was previously formulated by Allen, Lunenfeld, and Alexander (1971), in terms of *navigation* (macroperformance), *guidance* (situational performance), and *control* (microperformance).

CATEGORIZATION AND OPERATIONALIZATION OF DRIVING STYLE

In the research literature, driving styles are operationalized at different levels of specification, from single indicators, like speeding or hard acceleration, to very general concepts, for example, "aggressive driving" or "risky driving," which may be based on a combination of several more specific behavioral indicators. For classification of driving styles, we therefore suggest a distinction between *global* and *specific* driving styles. Based on the framework we propose, one potentially useful way to conceptualize global driving styles is in terms of their underlying motives. Thus, for example, aggressive driving may be manifested in a variety of different behaviors, such as frequent honking, tailgating, gesturing, and so on. These behaviors could all possibly be related to the same underlying excitatory motive of punishing other road users for a perceived offense. A specific driving style refers to a specific habitual behavior, such as speeding. Thus, a global driving style generally constitutes a set of specific driving styles. The operationalization of a driving style (i.e., the specification of how it is measured) is here called an *indicator*.

Thus, a global driving style is generally operationally defined on the basis of several indicators, whereas a specific driving style is defined by a single indicator or a few indicators. Since the number of indicators may vary from one to several, it is more appropriate to consider the global versus specific more as a continuum than as a dichotomy. Finally, the term *measure* refers to the basic signals that are used as input for the calculation of indicators. This scheme is illustrated in Figure 2.

Based on this general classification scheme, and the conceptual framework outlined previously, the remainder of this section reviews and discusses some common global and specific driving style categories found in the literature.

Global Driving Styles

Concerning global driving styles, *aggressive driving* is a very common term used both in research literature (e.g., Shinar, 2007) and in popular publications to describe what is considered typical maladaptive and risk-related behavior in traffic, and it is probably the single driving style concept that has received most attention in road safety research. For a general discussion about this concept, we refer to Shinar (2007, chap. 9) and Persak (2011). Shinar (2007) distinguishes between "hostile aggression" and "instrumental aggression." The former category comprises hostile reactions directed toward

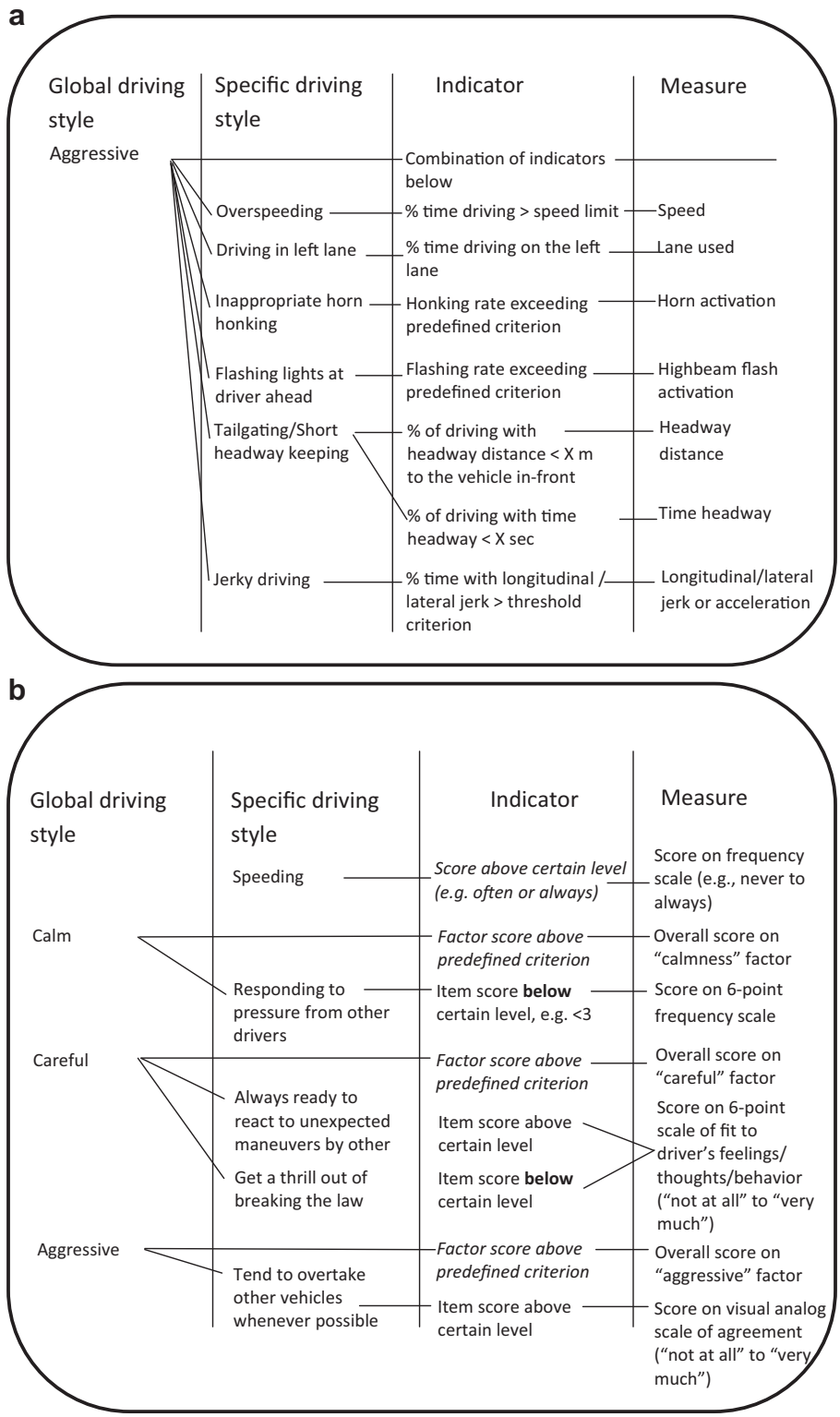

Figure 2. Examples illustrating relationships between driving styles, indicators, and measures. (a) Examples from driving observation data. (b) Examples from questionnaire data. The examples are based on the reviewed literature (see text for references).

other road users that serve no mobility purpose, such as verbal abuse, physical attack, or hand gestures. The terms *road rage* (see Shinar, 2007), *driving vengeance* (Wiesenthal, Hennessy, & Gibson, 2000), and *angry driving* (e.g., Dahlen & Ragan, 2004) seem to refer to this aspect of aggressive driving. By contrast, instrumental aggression comprises behaviors with the intention to reach the goal faster, such as weaving, tailgating, speeding, or running red lights. Thus, honking may be either hostile, if done to "disapprove" of other road users' behavior after an action, or instrumental if carried out to influence other road users to do something (for example, honking at a driver who is late to start when a traffic light turns green). On the basis of the proposed framework, these two forms of aggressive driving reflect different underlying motives (retaliation and expediency, respectively) although their constituent sets of specific driving styles partly overlap. Instrumental aggression seems strongly related to the concept of "impatience in driving," one of the factors of the Ishibashi et al. (2007) Driving Style Questionnaire, which also reflects motives related to expediency.

Aggressive driving has mainly been studied based on self-report instruments. Some questionnaires were designed explicitly for measuring driving aggression in general (e.g., Sümer, Ozkan, & Lajunen, 2006) or hostile aggression in particular, such as "driving vengeance" (Wiesenthal et al., 2000) or "driving anger" (Deffenbacher, Lynch, Oetting, & Swaim, 2002; Deffenbacher, Oetting, & Lynch, 1994). In addition, some of the general self-report measures of driving styles contain driving aggression as one of several factors, often based on factor analysis of a large number of questionnaire items. For example, "angry driving" is one of the eight driving styles measured by the Multidimensional Driving Style Inventory (MDSI) by Taubman-Ben-Ari, Mikulincer, and Gillath (2004), and "aggressive driving" is a subscale of the Dula Dangerous Driving Inventory (Dula & Ballard, 2003). Driving aggression is also one of the factors of the Driver Behaviour Inventory (DBI; Gulian, Matthews, Glendon, Davies, & Debney, 1989), measured, for example, by the item "When irritated, I drive aggressively." Furthermore, "aggressive violations" is one of the commonly described factors of the Driving Behaviour Questionnaire (DBQ; Parker, Reason, Manstead, & Stradling, 1995; Reason, Manstead, Stradling, Baxter, & Campbell, 1990). It seems like most of these terms refer mainly to the "hostile" variety of aggressive driving discussed earlier.

Deviant and risky driving. Although there is probably a high correlation and overlap between aggressive driving styles and other types of risky or deviant driving styles, it is possible to drive in a risky manner without necessarily being aggressive (in the "hostile" sense). Various concepts in the driving style research literature refer to such behavior. The MDSI (Taubman-Ben-Ari et al., 2004) contains a factor named "risky driving style," and the same term is also used by Richer and Bergeron (2009) and by Dula and Ballard (2003). Other related terms found in the research literature include "reckless and careless" driving style (Ishibashi et al., 2007) and "dangerous" driving (Knipling et al., 2004).

Some studies refer to the deviance aspect of driving as a characteristic of risky driving styles. Batool, Carsten, and Jopson (2012), in a discussion of road safety in Pakistan, used the term *deviant driving styles* as a generic concept, and Sakaguchi (2003) talks about "unusual behaviour" as a common term to describe his findings for a series of more specific driving style indicators. "Deviance" is also one of the six factors of the French, West, Elander, and Wilding (1993) Driving Style Questionnaire (DSQ), measured by items like "Do you overtake on the inside?" or "Do you ever drive through a red traffic light?" In terms of our framework, the deviance concept may be interpreted as referring to a situation where driving habits deviate from socially accepted norms.

Defensive driving. Although the focus in driving style research tends to be on the negative and risk-related driving styles, it is also important to consider the opposite end of the risky–safe continuum. An example of a common term to denote a positive driving style is *defensive driving*, which has been studied particularly in the context of driver training (e.g., Lähdeniemi, 1995; O'Day, 1970). In relation to environmentally friendly

driving, defensive driving is often conceptualized as the contrast to aggressive driving (see, e.g., Tzirakis & Zannikos, 2007).

Concentrated and focused driving. Some studies have focused on driving styles as related to concentration and attention to the driving task. The DSQ by French et al. (1993) contains a factor that the authors named "focus," measured primarily by items like "Do you find it easy to ignore distractions?" and "Do you ignore passengers?" A similar factor of the Gulian et al. (1989) DBI is "driving alertness." According to our framework, this factor can be related to motives for engaging in secondary (distracting) tasks. It may be suggested that the strength of these motives are to a large extent determined by the emotional value of the secondary task to the driver (Engström, Victor, & Markkula, 2013). For example, a driver who has developed an "addiction" to texting/social media would be expected to be more inclined to habitually take the eyes off the road in order to interact with a smartphone than a driver who seldom texts or uses social media.

As shown by the review so far, it is clear that there are many different terms that have been used to label global driving styles but little consensus on their precise meaning. In general, these terms and concepts seem to derive from everyday language and seem to have been coined more or less independently by each author, often in the context of the development of a self-report instrument. As a result, the terms used (such as aggressive, risky, reckless, deviant, defensive, or focused driving) seem to represent somewhat different concepts that are difficult to reconcile and generalize. At the most general level, one may distinguish between aggressive/risky and defensive/careful/focused driving styles, whereby the former refers to habitual driving behavior dominated by excitatory motives (focusing on accomplishing goals) whereas defensive driving refers to habitual behavior dominated by inhibitory motives (focusing on avoiding risk).

A key advantage of conceptualizing global driving styles based on underlying motives is that it is precisely these motives that need to be targeted in order to modify an unsafe driving style (as further discussed later). However, a possible disadvantage is that this scheme does not seem to account for driving styles that do not originate from specific motives. Thus although most global driving styles addressed in the literature reviewed here seem to be associated with driver motives, potential alternative classification criteria may also be considered.

It could also be noted that some of the self-report scales contain a mixture of "true" driving styles, referring to habitual behaviors, and more subjective states or conditions, which should rather be classified as background factors than as driving styles (we discuss the relationship between driving styles and background factors in a subsequent section). For example, in the Ishibashi et al. (2007) Driving Style Questionnaire, some factors rather reflect self-rated driving skills (confidence in driving skills), attitudes and values (importance of automobile for self-expression), or emotional states or dispositions (anxiety about traffic accidents). Similarly, in the MDSI (Taubman-Ben-Ari et al., 2004), some of the factors do not count as driving styles by our definition, for example, the *anxious* and *distress-reduction* categories are questionable, because they refer to emotional states rather than to driving behavior. This broad definition of driving style behaviors seems to be intended by the authors, because participants were asked to rate the items in relation not only to their behavior but also to their feelings and thoughts.

Specific Driving Styles

Specific driving styles refers to specific habitual, consistently recurring behaviors and can be grouped into the following common categories: longitudinal control, lateral control, gap acceptance, visual behavior, errors and violations, and other. Examples of driving styles and measures within each of the categories are shown in Table 3, and some of the examples are further elaborated in the following text. It should be emphasized that the driving behaviors listed under the "Driving Styles" column in Table 3 are considered driving styles only if they occur in a consistent manner across driving occasions, as implied by our definition. When occurring occasionally, they are considered as driving behavior only.

Concerning longitudinal control, *speed* and its derivative *acceleration* seem to be the most

TABLE 3: Examples of Specific Driving Styles and Related Measures, Grouped in Categories, With References

Driving Style	Measures	References
Longitudinal control		
Speeding and/or hard braking/acceleration	Speed Acceleration	Paefgen, Kehr, Zhai, & Michahelles, 2012; Aljaafreh, Alshabatat, & Najim Al-Din, 2012; Eren, Makinist, Akin, & Yilmaz, 2012; Johnson & Trivedi, 2011; Elander, West, & French, 1993; af Wåhlberg, 2006; Robertson, Winnett, & Herrod, 1992; Sümer, Ozkan, & Lajunen, 2006; de Waard, Dijksterhuis, & Brookhuis, 2009; Keskinen, Ota, & Katila, 1998; Persak, 2011; Ericsson, 2000; Quenault, 1967
Jerky driving	Jerk	Murphey, Milton, & Kiliaris, 2009; Bagdadi & Várhelyi, 2011; Desai & Haque, 2006
Tailgating	Time headway Distance headway	MacAdam, Bareket, Fancher, & Ervin, 1998; Cho, Nam, & Lee, 2006; Xiong, Boyle, Moeckli, Dow, & Brown, 2012; Underwood, 2013
Lateral control		
Left-lane preference	Lane choice	Reimer et al., 2013
Variable lateral position	Steering angle Lateral position	Ungoren & Peng, 2005; Cho et al., 2006; Yan, Radwan, & Guo, 2007; Underwood, 2013
Speeding in curves	Lateral acceleration	Robertson et al., 1992; Reymond, Kemeny, Droulez, & Berthoz, 2001; Lajunen, Karola, & Summala, 1997; Aljaafreh et al., 2012
Gap acceptance		
Late crossing	Time between vehicles at crossings	Keskinen et al., 1998; Yan et al., 2007
Frequent overtaking	Passing gap when overtaking	Farah, Bekhor, Polus, & Toledo, 2009
Visual behavior		
Fixating close to own vehicle	Area of fixation	Mourant & Rockwell, 1970, 1972
Frequent long looks away from road	Direction of looking/ eyes-off-path time Fixation length and frequency	Serafin, 1994; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003; Underwood, Crundall, & Chapman, 2002; Crundall & Underwood, 2011
Failure to look in side mirror during lane change	Mirror checking	Quenault, 1967; Crundall & Underwood, 2011
Errors and violations		
High frequency of respective actions	Failing to use indicator Driving through red traffic light Violating stop sign Use of wrong gear	Quenault, 1967; Reason et al., 1990
Other		
High frequency of respective actions	Unusual maneuvers Near accidents Inappropriate honking Making gestures to other road users	Quenault, 1967; Shinar, 2007
Leaning on steering wheel	Driving posture	

frequently used measures of driving styles. Although risky driving styles are mostly associated with high speeds, there are some indications that even lower-than-normal speeds may be risky. For example, de Waard, Dijksterhuis, and Brookhuis (2009) investigated merging speeds for drivers on a motorway entrance ramp, on the assumption that merging at a lower speed could make the maneuver more risky. Habitual speeding may be related to a range of excitatory motives, such as expediency, social group pressure, and hedonistic motives, such as seeking the thrill of speeding or conforming to group norms (e.g., following the pace of traffic even if it is above the legal speed limit). Failure to keep posted speed limits may also be due to inattentive driving, for example, when failing to notice a temporary shift in speed limit due to not paying sufficient attention. Unusually low speeds may be related to inhibitory motives (e.g., risk aversion), which may be most common among older drivers.

Jerky driving. Jerky driving, defined as a driver's speed of accelerating or decelerating (i.e., jerk profile), was used by Murphey et al. (2009) as an indicator of individual driving styles. Bagdadi and Várhelyi (2011) found that the jerk at the beginning and end of a braking maneuver was the best jerkiness indicator of safety-critical driving behavior.

A different approach to jerkiness was taken by Desai and Haque (2006), who introduced the concept of "spikiness index," based on the jerk profile. They hypothesized that this index can be used both as an indicator of alertness and as a signature of individual driving styles.

Robertson, Winnett, and Herrod (1992) equipped a vehicle with a dual-axis accelerometer in order to investigate "acceleration signatures" for a sample of 10 drivers during driving through a predefined route. The acceleration signatures were based on combined registration of lateral and longitudinal accelerations. The same measure has subsequently been used in another driving style study by Lajunen, Karola, and Summala (1997). Like speed, these types of jerky driving indicators are quite unspecific with respect to the motives underlying the behavior and could reflect aggressive driving as well as hurried/impatient or inattentive driving. However, it could also reflect an individual automatized control strategy that developed more or less independently of specific motives.

Based on *headway* measurements, MacAdam, Bareket, Fancher, and Ervin (1998) formulated a "driving aggressivity index" based on the relative prevalence of the behavior categories "closing in rapidly," "closing in," and "following" as opposed to "falling behind" or "falling behind rapidly." Similarly, Fancher et al. (1998) considered drivers as either flow conformist, extremist, hunter/tailgater, planner, or ultraconservative, based on measurements of headway and closing speed in an intelligent cruise control field operational test. These types of indicators seem to be somewhat more specific than speed and jerkiness, and extreme tailgating appears like a strong indicator reflecting hostile aggressiveness and/or impatient driving. The habitual adoption of a comfortable headway during normal driving is also influenced by the socially accepted norm in a country or region. The choice of short headways could be partly explained by the presence of excitatory motives (e.g., time pressure, social pressure).

Concerning lateral control, examples of driving styles related to steering and lane keeping are highly variable lateral position and tendency to cut across the central lane marker on bends. The former is indicative of inattentive driving, in particular, visual distraction (Engström, Johansson, & Östlund, 2005), whereas the latter may rather reflect motives related to expediency. A driving style related to *lane choice* is excessive or unnecessary driving in the left lane (which in most countries with right-hand traffic is recommended or reserved for overtaking), indicated by, for example, percentage of driving time in left lane. *Lateral acceleration* is a particularly interesting indicator, since it reflects speed choice behavior in curves, relative to the curve radius, which is a likely indicator of crash risk, especially under low-friction conditions. It is one of the parameters determining the "acceleration signature" developed by Robertson et al. (1992), described earlier. Reymond, Kemeny, Droulez, and Berthoz (2001) refer to previous studies showing that drivers adjust their speed in curves so that maximum lateral acceleration is lower at high speed (i.e., in less sharp curves),

and they suggest that the relationship between curvature and maximum acceptable lateral acceleration can differentiate between "normal" and "fast" driving styles. High values of lateral acceleration would be expected to correlate with speeding and generally seem to be driven by similar driver motives (i.e., expediency, social group pressure, thrill of speeding, etc.).

Gap acceptance. Gap acceptance behavior may refer, for example, to acceptance of time gaps when entering a crossing traffic stream, or time gap to an oncoming vehicle when overtaking a lead vehicle. An example of a driving style based on this measure is accepting short time gaps when entering a main road. Short time gaps seem to mainly reflect motives related to expediency.

Research on individual differences in *visual behavior* has mainly focused on differences between novice and experienced drivers in scanning patterns, based on eye movement recordings. This field of research has been strongly influenced by the early studies by Mourant and Rockwell (1970, 1972), where a main finding was that novice drivers tended to concentrate their visual search in the area just ahead of the vehicle, whereas more experienced drivers looked farther ahead. Subsequently, eye fixation has been investigated in several studies of how both age and experience influence the visual behavior of drivers (Serafin, 1994; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003; Underwood, Crundall, & Chapman, 2002). For an overview of this research area, see, for example, Crundall and Underwood (2011).

It may be suggested that these indicators mainly reflect the development of increasingly automatized and efficient visual scanning with increased experience (driven by the general reinforcement process in Figure 1), with an increased tendency to focus scanning on areas where the most relevant information is expected. By contrast, visual behavior related to the engagement in secondary tasks can be viewed as a direct indicator of inattentive driving. As discussed earlier, this behavior may be considered as a driving style to the extent distracted behavior has developed into a habit. As noted earlier, it may be predicted that the risk for habitual distraction is greatest for drivers who developed an addiction to tasks such as texting or accessing social media on a smartphone.

A wide range of specific driving *errors and violations* that are not included in the categories discussed so far have been used to define driving styles, mainly in self-report studies using the DBQ (e.g., Reason et al., 1990) or similar instruments. Examples include driving through red traffic lights, failure to use indicator signal, failure to stop before stop sign, using wrong gear, and so on. According to Reason et al. (1990), errors and violations are two distinct categories of unsafe acts. Errors are defined as "the failure of planned actions to achieve their intended consequences" (Reason et al., 1990, p. 1315), manifesting themselves either as *slips* and *lapses* ("the unwitting deviation of action from intention"; Reason et al., 1990, p. 1315) or *mistakes* ("the departure of planned actions from some satisfactory path towards a desired goal"; Reason et al., 1990, pp. 1315–1316). Violations, on the other hand, involve some intention to commit the unsafe act. It should be noted, though, that some actions that are violations in a legal sense may count as errors in a psychological sense, for example, when a driver unintentionally exceeds the speed limit or fails to observe a stop sign. Since errors and violation thus have different psychological explanations, they may also need different types of interventions.

Violations, such as intentionally running a red light, could generally be considered as due to excitatory motives (e.g., time pressure, group pressure) that are sufficiently strong to override the perceived risks related to committing the violation (e.g., losing one's driving license). To the extent that such violations are committed systematically, the behavior would qualify as a specific driving style. By contrast, the commitment of errors does not generally seem to qualify as a driving style unless they, for some reason, are not corrected and thus continue to be repeated.

Other driving styles. We assume that most specific driving styles listed in Table 3 may occur either as isolated habits or together with other habits and thus as part of global driving styles. For example, driving styles usually occurring as part of the global driving style *hostile aggression*, such as making gestures to other

road users or inappropriate honking, can be considered specific driving styles if they occur in isolation. We also assume that some specific driving styles, for example, seating posture or hand position, may occur without any connection to any of the global driving styles.

In addition to the driving styles discussed so far, future research may reveal additional examples of stable patterns of driving behavior that satisfy the definition of driving styles, both global and specific. With the growing amount of behavior observation data, data mining seems to be a promising approach for this purpose, as well as for validating self-report driving style indicators. For example, Constantinescu, Marinoiu, and Vladoiu (2010) used a data-mining approach including hierarchical cluster analysis and principal components analysis of several vehicle-based driving parameters and identified four different driving styles, which they described as aggressivity, speed, accelerating, and braking.

RELATIONSHIP BETWEEN SELF-REPORTED AND OBSERVED DRIVING STYLES

The ultimate indicators of a driving style are how a driver actually drives, and consequently the "golden standard" for a driving style measurement is unobtrusive observation of driving behavior. It is therefore an interesting issue to what extent different scores on self-report instruments are reflected in corresponding differences in observed driving styles.

West, French, Kemp, and Elander (1993) investigated correlations between observations by in-vehicle observers and self-reported driving styles using the DSQ and found high correlations for speed (Pearson correlations between .55 and .65) and also significant but moderate correlations for calmness (.39–.41), attentiveness (.29), and carefulness (.38).

Amado, Arikan, Kaca, Koyuncu, and Turkan (2014) compared errors and violations assessed by in-vehicle expert observers (through some observation forms) with participants' self-reported errors. The authors reported significant but low correlations between driver self-evaluations and some of the observed violations and errors: speed errors (r = .24), traffic light errors (r = .33), brake and gear errors (r = .30), and clearance and checking errors (r = .18). Overall, although some correlation was shown between self-assessed and in-vehicle observer ratings, the participants generally overestimated their own driving competence.

Ishibashi et al. (2007) found significant correlations between some of the factors of their Driving Style Questionnaire and observed driving style in a car-following study using an instrumented vehicle. The highest correlations were found with gas and brake pedal operations during deceleration. For example, "impatience in driving" was related to high brake pedal operation (r = .50) and close following (r = .66).

Farah, Bekhor, Polus, and Toledo (2009) found that the high scores on the MDSI Angry and Hostile Driving Style scale were significantly related to both higher speed (r = .32) and shorter passing gaps (r = –.20). More recently, Helman and Reed (2015) reported correlations ranging from .38 to .48 between the DBQ Violations scale and driving speed measured in a driving simulator.

It is well known that self-evaluations of behavior may be biased, both in driving and in other domains, for example, by tendencies in the direction of socially desirable responses (Crowne & Marlowe, 1960; Lajunen et al., 1997). Despite such tendencies, the significant associations with objectively measured behavior reported here imply that self-report instruments can still play an important role in driving style research.

ARE DRIVING STYLES RELATED TO CRASH RISK?

A crucial issue regarding driving styles is the practical implications of the individual differences. To what extent are driving styles related to crash risk, and which driving styles are the most important predictors? For some driving styles involving notoriously risk-related behavior at a strategic level, like driving without using a seat belt or driving under the influence of drugs or alcohol, the relationship to crash involvement or injury risk is obvious. Other driving styles at the strategic level, like route choice, may bear more subtle relationships to crash risk. The main issue to be discussed here, however, is possible relationships between crash

risk and driving styles at the tactical or operational level.

Quenault (1967) compared observed driving styles of a group of drivers convicted for traffic offenses with those of a control group and found significant group differences for the driving style measures mirror use, overtaking frequency, "unusual driving behaviour," and near accidents. This study, however, did not include any comparison between the different driving styles regarding strength of association with crash involvement history.

Concerning crash involvement, several of the studies discussed here have compared driving styles between groups of drivers with different crash involvement history. Although most studies are correlational or based on qualitative assessments of driving styles, differences between crash-involved and crash-free drivers may indicate causal relationships from driving styles to crash risk. An example is the old study by Tillman and Hobbes (1949) in which they found differences in observed driving behavior between taxi drivers with different crash records. Drivers with a high accident frequency tended to be easily distracted while driving and to be readily annoyed at other motorists on the road. As well, during the drive, they showed a disposition for horn honking and racing other cars away from a stoplight.

Authors of some studies investigated correlations with self-reported crash involvement. For example, West et al. (1993; West, French, & Elander, 1990) found positive correlations between self-reported crash involvement in the past 3 years and observed motorway speed (r ranging from .37 to .47 for different speed-based indicators) in a sample of 48 drivers.

Using the DSQ data from 711 drivers, French et al. (1993) showed that the driving styles speed, planning, and deviance (as defined by French et al., 1993) were all significantly related to self-reported crash risk. However, a multiple regression analysis showed that speed explained the effects of the other driving styles.

A review article by Elander et al. (1993) concluded that "with regard to driving style, faster driving and deviant driving behaviour are consistently associated with more frequent crashes" (p. 290). In support of this conclusion, they refer to, among others, the study of Wasielewski (1984) showing that unobtrusively recorded driving speeds for a sample of 6,638 cars were significantly related to state records of the drivers' crashes.

Af Wåhlberg (2006) compared various speed-related indicators regarding prediction of crash involvement among bus drivers. Recording equipment was installed in a fleet of buses, and speed and acceleration were recorded over a period of almost 3 years from about 250 drivers observed on average during 3.2 trips. The author concluded tentatively that "celeration behaviour" (an index based on acceleration and deceleration) was a better predictor of company-recorded crash involvement than other speed-based indicators. However, the author points out that this conclusion should be taken with great caution, because the difference between celeration and other speed-based indicators regarding correlation with crash involvement was not significant. Furthermore, there was a ceiling effect for maximum speed (speeds above 65 km/h were not measured), which could have attenuated the correlation with crash involvement for this variable. Using the same celeration index, Katsianis, Eliou, and Iliadou (2013) found a significant correlation (r = .39) with self-reported crash risk, but this correlation was not significant (this study was based on only 10 drivers). They did, however, find a significant correlation of .71 between "time spent accelerating" (on an urban road) and self-reported crashes per distance driven.

There are also studies showing only low and insignificant correlations between driving style measures and crash risk. For example, the original research with development and validation of the Dula Dangerous Driving Index (Dula, 2003) showed insignificant correlations on the order of r = .10 with crash involvement, although there were significant correlations with self-reported traffic tickets in the past 2 years.

Concerning the relationship between crash involvement and habitual errors or violations, de Winter and Dodou (2010) did a meta-analysis of studies using the DBQ, and they found significant, but low, correlations with self-reported crash involvement both for errors and violations. The correlations were slightly higher for

violations than for errors. The predictive value of violations for crash involvement is further shown by studies comparing criminal records between crash-involved and crash-free records. Junger, West, and Timman (2001) found that crash-involved drivers were about 5 times more likely to have a history of driving-related violations, compared to drivers without crashes.

Turetschek (2006) reported an investigation by Bukasa and Risser (1985) of how behavior assessed through the "Wiener Fahrprobe" was related to individual accident records and to accident types in 51 road sections along a standardized route. The results showed significant and moderately high correlations between the accident records and some behavior assessed by the observers. The two highest positive correlations with previous crash involvement was found for "exceeding speed limits" ($r = .35$) and "too short distance to car ahead" ($r = .33$), whereas negative correlations (indicating a protective effect) were found for "speed not exceeding speed limits and well adapted to situation" ($r = –.40$) and "early deceleration whenever deceleration becomes necessary" ($r = –.24$).

The study by Bukasa and Risser (1985) showed examples of both dangerous and protective driving styles. Whereas the focus of much driving style research tends to be on the dangerous driving styles, it is important to discuss which driving styles contribute most to preventing crash involvement. Defensive driving is an example of a driving style supposed to have such an effect. A meta-analysis by Elvik, Høye, Vaa, and Sørensen (2009) showed that defensive driving courses reduce crash risk by about 20% for professional drivers, which is clear evidence of a relationship between driving style and crash risk.

In summary, the studies reviewed in this section show clearly that several indicators of driving style can predict crash involvement. The clearest finding is that drivers whose driving style is characterized by frequent speeding and/or abrupt acceleration and deceleration have a higher crash involvement. That speeding is related to crash involvement is not surprising when considering the long-established relationship between speed and crash probability as well as severity. In the same vein, the driving styles characterized by low speed or slow acceleration/deceleration are associated with lower risk. There is a continuum ranging from protective driving styles, like "defensive" or "calm" on the low-risk end, to dangerous driving styles, like "aggressive" or "hostile" at the high-risk end. Speed is probably only one of the indicators explaining this variation. Beyond this general formulation of a continuum from low-risk to high-risk driving style, the available literature does not permit any ranking of the strength of relationships between the various driving styles and crash risk. There is a need for more research in order to map out these relationships in more detail in order to make quantitative estimates of the predictive power of different driving styles regarding driver crash involvement and to arrive at a clearer understanding of the behavioral mechanisms involved.

Thus, it could be possible to place each driving style on a continuum from low to high risk. To achieve this goal, there is clearly a need for more studies using actual crash involvement rather than self-reports for investigating the predictive power of driving styles. Naturalistic driving analysis could be expected to play a key role here, in particular if the data include a sufficient number of actual crashes that could be related to driving style indicators. A recent, simple, and innovative approach is using smartphone technology for the acquisition of a large amount of behavioral data in naturalistic settings. This approach is now being used increasingly in research on driving styles (Eren, Makinist, Akin, & Yilmaz, 2012; Hong, Margines, & Dey, 2014; Johnson & Trivedi, 2011; Paefgen, Kehr, Zhai, & Michahelles, 2012).

FACTORS ASSOCIATED WITH DRIVING STYLES

Individual Factors

Gender. Corbett (2007) reviews research on gender differences in car-related crimes and convictions as well as self-reported offenses. After pointing out the well-known overall gender gap in driving styles, resulting in a higher rate of offenses and convictions among males, she concludes that female driving styles are more heterogeneous and that there is a "ladette" subgroup of young female

drivers whose driving style is more similar to that of young males.

A comparison of young male and female drivers' attitudes and self-reported traffic behavior in Finland between 1978 and 2001 (Laapotti, Keskinen, & Rajalin, 2003) showed that the gender difference in traffic offenses (fewer offenses and lower crash rate among females) had not decreased over the years. For some indicators (for example, attitudes toward traffic rules and safe driving), the difference had even increased somewhat. On the other hand, Boyce and Geller (2002) found no significant gender differences regarding risky driving style.

Reagan, McClafferty, Berlin, and Hankey (2013) studied driving style at a more strategic level, namely, seat belt use, using data from the 100-Car Naturalistic Driving Study. Based on more than 86,000 trips, 134 drivers (primary and secondary) were grouped into infrequent (using seat belts on 30% or less of all trips), occasional (40% to 85%), and consistent (more than 95%) seat belt users. They found that 13.1% of female drivers (eight out of 61 drivers) were infrequent users, compared to 20.5% of male drivers (15 out of 73 drivers). Although this gender difference was not statistically significant, it is suggestive of less frequent seat belt use among male drivers, which is consistent with other studies showing a more risky driving style among males. The authors point to the small and possibly biased sample as a limitation of this study.

Kleisen (2011) used the MDSI to compare driving styles between male and female young drivers, finding that females scored higher on the positive driving styles ("patient" and "careful"), whereas males were characterized more by negative driving styles ("risky," "angry," "high-velocity").

Gender differences in driving style seem to vary with driving conditions. For example, Ericsson (2000) found that the tendency of men to accelerate harder than females was clearly more pronounced on a local feeder road in a residential area compared to other road types. Interactions between gender and road type were observed also in a site-based study by Aronsson (2006). She found very small differences between male and female drivers in average speed over a section consisting of a combination of road types. However, males tended to drive slightly faster than females on suburban streets, whereas females drove faster on arterials and urban streets. In addition, females tended to keep larger headways than males on suburban roads.

Although these results on the relation between gender and driving style are somewhat mixed, existing studies indicate a general tendency for men to adopt a riskier driving style than women. This finding may possibly be partly explained by innate biological factors, such as testosterone level (Evans, 2006), but it seems likely that also sociocultural factors (e.g., living up to the culturally defined male "ideal"; see Skippon, Diels, & Reed, 2012) play a role.

Age and experience. Keskinen, Ota, and Katila (1998) observed speed, acceleration, time gaps, and driver head movements of both turning drivers and drivers driving through an intersection, and observers judged the age of the drivers. They found lower acceleration and longer turning times in intersections among older compared to younger drivers, resulting in shorter time gaps for the older drivers. Similarly, Yan, Radwan, and Guo (2007) studied driving behavior related to left-turn gap acceptance in a simulator and found that older drivers (56 to 83 years old), especially female drivers, had more problems with left-turn maneuvers, compared to younger drivers. At the same time, they displayed a conservative driving attitude as a compensation for reduced driving ability.

De Waard et al. (2009) found, in a simulator study, that older drivers (65 years and older) kept a lower speed than younger drivers when merging into heavy motorway traffic. They point out that this lower speed may make the merging maneuver more risky in real traffic. In this study, they manipulated length of the acceleration lane as well as presence of a driver support system that encouraged drivers to speed up if the speed was too low, both of which facilitated merging.

Reimer et al. (2013) compared three age groups regarding lane choice and changing in real traffic using an instrumented vehicle. They found that drivers in their 60s were less likely to change lanes and to drive on the leftmost lane

compared to younger drivers. They also found that increased cognitive workload decreased frequency of lane change in all age groups.

Underwood (2013) studied changes in driving styles between two age groups of novice drivers (17–19 years and 23–44 years) over the first 6 months after they acquired a full license, in order to assess effects of driving experience. The drivers were tested in an instrumented vehicle in real traffic on three occasions: 0, 3, and 6 months after passing the driving test. The drivers tended to increase their speed over the three drives, as well as their frequency of cutting across the central lane marker on bends. The older group of novice drivers showed stronger indications of becoming more cautious with driving experience, as shown by increased headway and more glances in the mirrors at critical points, compared to the younger group. The author comments that the observed changes across the three drives are partly an effect of general driving experience over the 6-month duration of the test period but that there may also be an effect of familiarity with the instrumented vehicle and the testing procedure. Thus, to the extent that the effects are due to general driving experience, there seems to be an interaction between age and driving experience regarding driving style.

Age effects on driving styles were also observed by Boyce and Geller (2002). They measured several variables (e.g., vehicle speed, following distance, and seat belt use) during an on-road test with an instrumented vehicle and found that young age (between 18 and 25 years old) is one of the predictors of risky behaviors (speeding and following distance).

The previously mentioned study by Reagan et al. (2013) of seat belt use, using data from the 100-Car Naturalistic Driving Study, also involved looking at age differences and showed that younger females (under 40 years) were more likely to be infrequent seat belt users than females over 40. For males, there was no significant age effect.

Older studies of age differences in driving styles were summarized by Elander et al. (1993), who conclude that faster speed is associated with younger drivers and that in addition, "several observational studies have found relationships between youth and other potentially risky driving styles" (p. 287). The latter include shorter headways to vehicle in front, accepting shorter time gaps when pulling out into traffic, and running yellow lights.

This research clearly indicates that young drivers generally adopt more aggressive/risky driving styles and older drivers tend to be more cautious than average. The latter may, however, lead to risky situations due to the problems of some older drivers to keep up with the traffic pace. This research indicates that the balance between excitatory and inhibitory motives changes with age, with a stronger excitatory dominance for young drivers. Stronger excitatory motives for young drivers may be due to a range of factors, including biological dispositions or group pressure from peers for young drivers to "show off," not wear a seat belt, and so on. Weaker inhibitory motives in young drivers may be due to weaker risk perception due to less driving experience or a lower level of cognitive maturity among younger drivers (at least for mid-teenage drivers). Based on a literature review, Casey, Jones, and Somerville (2011) suggest that the high prevalence of impulsive and risky choices among adolescents can be explained as "an imbalance between a heightened sensitivity to motivational cues and immature cognitive control." Similarly, the more defensive driving styles typically adopted by older drivers could possibly also be explained in terms of weaker excitatory motives for risky behavior (e.g., biological factors related to aging, such as lower testosterone level, and sociocultural norms for how older people are expected to behave) as well as relatively stronger inhibitory motives (e.g., a need to compensate for biomechanical or perceptual impairments).

Personality and lifestyle-related factors. Authors of some studies have looked at associations between driving styles and personality factors. For example, Poo and Ledesma (2013) found that several personality traits correlated significantly with MDSI driving style factors. Positive correlations were found between self-reported impulsive sensation seeking and risky, angry, and dissociative driving styles; between aggression-hostility and risky and angry driving styles; and between neuroticism-anxiety and

dissociative driving style. Self-reported impulsive sensation seeking and aggression-hostility correlated negatively with careful driving style.

Skippon et al. (2012) present two studies of personality and driving styles and discuss their results in the perspective of driving styles as indicators of reproductive fitness:

> Driving in a particular style does indeed convey information about the five-factor personality profile of the driver to other people. It also confers information about the likely age, gender and relationship status of the driver. So, for instance, if a young male is motivated to signal his youth, maleness and spontaneous, dominant personality to females, the faster, riskier, more aggressive driving styles represent good ways to do so; females will read and understand the signals. Likewise an older female might make use of Patient or Cautious driving styles to signal maturity, agreeableness and propensity for long-term relationships. (p. 370)

One of the studies consisted of having participants read descriptions of the eight driving styles of the MDSI and then judging how well each of a list of 18 personality and behavior characteristics would fit a driver who would normally show the behaviors described by the driving styles. The characteristics to be judged consisted of personality traits based on the five-factor theory as well as attributions of status, gender, age, relationships, and attractiveness. The five-factor theory—"Big Five"—is a widely accepted model of human personality, comprising the dimensions openness, conscientiousness, extraversion, agreeableness, and neuroticism. Some of the findings were that the "cautious" driving style was associated with high scores on conscientiousness and agreeableness, whereas the "angry" driving style scored low on the same dimensions. The findings were interpreted as tentative support for the ideas quoted previously.

Further support for a relationship between negative driving styles and personality factors comes from studies by Lajunen and Summala (1995) and Boyce and Geller (2002). Lajunen and Summala (1995) found that high scores on the driving aggression factor of the DBI were related to neuroticism ($r = .56$), Type A personality (described by Friedman, 1996, as characterized among other things by overambitious and impatient behavior; $r = .32$), low self-esteem ($r = –.34$), and a low sense of coherence ($r = .52$). Boyce and Geller (2002) found that younger age (between 18 and 25 years old) and Type A personality are predictors of risky behaviors. Type A correlated significantly with mean speed ($r = .33$) and mean following distance ($r = –.30$).

Concerning lifestyle, authors of two Danish studies (Møller & Haustein, 2013; Møller & Sigurðardottir, 2009) examined associations between driving style, as measured by a 14-item customized questionnaire, and leisure activities. They found that the driving style factors thrill and anger were most strongly related to the lifestyle factors "cruise around in a car with friends" and "driving to friends."

As shown by several studies, personality characteristics are clearly associated with driving style. More specifically, the results seem to indicate that drivers with certain personality types (e.g., Type A) are particularly disposed toward risky driving behaviors. In terms of the present framework, this finding can be understood as an association between those personality types and stronger excitatory motives for risky behaviors. However, the actual biological and psychological mechanisms underlying this relation are still unclear.

Cognitive style. Kleisen (2011) found that driving styles of young drivers, as defined by the MDSI, were significantly related to scores on a questionnaire about *thinking styles*. Thinking style is related to the more common concept of *cognitive style*, although Kleisen consider those as different categories. Out of 13 thinking styles, three ("executive," "hierarchic," and "conservative" thinking styles) correlated positively and significantly ($p < .001$) with the "patient" and "careful" driving styles. Hierarchic thinking, which is characterized by multitasking and multiple goals with different priorities, showed a stronger association with the positive MDSI driving styles in female drivers than in males. This result suggests the notion that drivers with stronger executive-control abilities are better equipped to resist momentary impulses for

potentially unsafe behaviors (e.g., unsafe overtaking, speeding, hostile aggression, or taking the eyes off the road to send a text message).

Sociocultural Aspects

Social network and organizational culture. Based on our framework, it is expected that the shared values within groups, such as families and friends or organizations (e.g., the attitude toward unsafe driving among friends or the safety policies adopted in a truck fleet), affect drivers' motives and hence influence driving style. This notion is supported by existing data. Taubman-Ben-Ari and her colleagues found significant associations between parents' and offspring's driving style (Taubman-Ben-Ari, Mikulincer, & Gillath, 2005). In another study of 413 pairs of intimate partners (Taubman-Ben-Ari, 2006), significant associations were found between driving styles of couples. In discussing results from these studies, the authors focused on the importance of intrafamilial transmission of driving styles as a basis for planning and designing effective safety interventions. Further studies by the same authors focused on the relationship between family climate and the driving styles of young drivers (Taubman-Ben-Ari, 2010; Taubman-Ben-Ari & Katz-Ben-Ami, 2012, 2013), finding that "positive aspects of the parent-child relationship and high levels of conformity to authority were related to greater endorsement of the careful driving style" (Taubman-Ben-Ari & Katz-Ben-Ami, 2012, p. 1). Correlations in driving styles between parents and children have been found also by Bianchi and Summala (2004).

Social influence seems to be important for driving styles especially among young people. For example, Møller and Haustein (2014) found that young drivers' perception of speeding among their friends was by far the most important predictor of own speeding behavior, compared to other possible predictors, like education, age, car use, history of crashes and violations, attitudes to speed limits, and perceived crash risk.

It has been shown in several studies that there is a relationship between safety culture or safety "climate" of an organization and the risk of accident involvement among its employees (see, e.g., Nahrgang, Morgeson, & Hofmann, 2011, for a meta-analysis of relevant studies). It seems reasonable to assume that this relationship is mediated to a large extent by effects of safety climate (i.e., values related to road safety) on driving styles. Recent support for this assumption comes from a study by Zohar, Huang, Lee, and Robertson (2014), who showed that a low frequency of hard-braking events among long-haul truck drivers was related to a positive assessment of the safety climate of their organization.

National and regional differences. The road safety values associated with a country or region would also be expected to significantly influence driving styles adopted. An interesting approach to national and regional differences in driving style is the "social accident" model proposed by Factor, Mahalel, and Yair (2007). They discuss interaction between different social groups in traffic from a sociological perspective, stating that drivers belonging to different social groups interpret a given situation differently and that this varied interpretation may result in conflicting decisions, possibly leading to crashes. The article by Factor et al. refers to several previous studies showing systematic differences in traffic behavior between drivers of different nationalities. For example, Gregory (1985) studied driving characteristics in Egypt, and Edensor (2004) compared driving habits between Britain and India. Both India and Egypt have a lower level of road traffic legislation and enforcement than Western countries, and this difference seems to result in culturally determined informal rules. For example,

> in Alexandria, [Egypt,] when a driver wishes to proceed . . . by pulling out into traffic . . . from a side street, he will appear not to wait for an open space in the mass of movement, but will simply plunge ahead. The abstract conception that a space will eventually open up for him is not considered. (Gregory, 1985, p. 344)

Concerning India, the road traffic system is characterized by informal conventions and norms for driving, possibly due to a paucity of formal rules:

> For instance, many vehicles lack rear-view mirrors and so the monitoring of

> traffic behind is usually not carried out. This means that it is necessary to sound the horn to warn any vehicle of a desire to overtake, and this has become accepted custom, irrespective of the presence or not of mirrors. (Edensor, 2004, p. 114)

Indirect evidence of national differences comes from a recent comparison of traffic safety culture between China, Japan, and the United States (Atchley, Shi, & Yamamoto, 2014). Although the authors do not explicitly discuss driving styles, they conclude that the different crash risk records of the three countries are related to different cultural values. Whereas China is characterized by an emerging driver population and cultural values resulting in aberrant driving behaviors and many crashes, Japan has a more established driver culture with a stronger emphasis on risk reduction. In the United States, the focus on individual freedom leads to choices that result in higher crash risk than in some other Western countries.

Two additional articles addressed road safety and driving styles in Pakistan and Slovenia, respectively. Batool et al. (2012) did a qualitative study of road safety in Pakistan, consisting of semistructured interviews with government officials, researchers, and road users in order to map characteristic deviant driving styles in the country as well as needs for road safety measures in general. Regarding the cultural aspect of driving styles, the following conclusion seems pertinent:

> There is no inclination among the population in Pakistan toward safe driving habits. The main point of contention here is the kind of safety culture that allows bad driving habits to develop. In the opinion of study participants, if you have to drive in the country, you have to blow your horn, and you must overtake fellow drivers or neglect their right of way. Even if people try to follow the rules, society forces them to be involved in unsafe practices. (Batool et al., 2012, p. 45)

Persak (2011) discussed human factors aspects of road crashes and dangerous driving in Slovenia, concluding among other things that driving aggressiveness and other psychological characteristics of drivers are major problems and that the "Slovene national personality profile" provides favorable conditions for deviant traffic behavior, like fast driving styles. Social desirability seems to be one explanation of fast driving, given that this behavior is viewed positively by the Slovene society.

Thus, there seems to be convincing evidence for the influence of national or regional culture on the driving styles adopted in the region. We refer to the article by Factor et al. (2007) for additional references to studies of differences between countries.

Technological Factors

In presenting our conceptual framework, we pointed to the possibility that driving styles may be influenced by technological factors. There are several studies showing that drivers adapt their behavior to various characteristics of the vehicle or the traffic environment. For example, when antilock braking systems were first introduced, it was shown that some drivers changed their driving behavior. Among the observed behavioral changes was a tendency to keep shorter headways (Sagberg, Fosser, & Sætermo, 1997).

However, for such a behavioral adaptation to count as driving styles according to our definition, it has to be shown that it is a relatively permanent change in behavior and that it differs between (groups of) drivers. Future research is needed to determine the degree to which individual drivers adapt differently to, for example, in-vehicle driver information and support systems. If such differences are found, it is an interesting question to what extent the technological factors interact with the other driver background factors discussed earlier, in explaining driving styles. Such knowledge will be important for possible applications of technological systems for modifying driving styles, a topic that will be discussed in the next section.

In summary, the studies reviewed in this section clearly indicate that driving style is potentially influenced by a range of factors, from individual characteristics (gender, age, cognitive style, and lifestyle) to group/organizational

values and national/regional culture. Thus, it seems clear that driving styles often develop through the joint influence of a large number of individual, sociocultural, and technological factors. However, further research is clearly needed to better understand the precise mechanisms for how these different factors influence driving style and how they may interact.

APPLICATIONS OF DRIVING STYLE RESEARCH

Understanding driving styles is of great interest to many businesses (e.g., automotive industries and insurance companies) as well as to the drivers themselves, given that driving style affects fuel consumption, vehicle maintenance bills, insurance cost, safety, and so on. Today a rapidly growing number of companies offer driver behavior profiling, coaching, and safety management services targeting commercial vehicle fleet operators as well as the insurance industry. The trend to link insurance premiums to driving style can be viewed in the larger context of usage-based insurance or pay-as-you-drive schemes (see, e.g., Ellison, Bliemer, & Greaves, 2015; Ellison, Greaves, & Bliemer, 2015).

A key application of knowledge from driving style research is in the development of methods for modifying driving style. Despite driving styles being, by definition, "relatively stable" characteristics of the driver (Saad, 2004), some approaches can be used to change driving styles, aiming to eradicate maladaptive (negative) driving styles and reinforce adaptive (positive) ones. Those approaches include driver training and education, increasing awareness of dangerous situations, and behavior-based safety (BBS) techniques.

Driver training and education is a common technique to change driving style. Gregersen (1994) compared two groups of learner drivers, one group receiving training only by a layperson (most often a parent) and the other group receiving a combination of training by a layperson with traffic school instruction. The self-reports of driving style, collected after the training, showed a small difference in the direction of more careful driving style in the group receiving professionally supported training. Further evidence of training effects on driving styles comes from a meta-analysis of courses in defensive driving (Elvik et al., 2009), showing a decrease in crash risk by about 20% among professional drivers.

Letting drivers see and study their own history of driving data is another method that could be used to modify driving behavior toward safer driving styles, as shown by Takeda et al. (2011). Their results suggest that the drivers' ability to understand dangerous situations can be improved by using driving data, as indicated by a 50% reduction in the number of dangerous events for a group of "nonexpert" drivers, compared to a much smaller reduction in a group of "expert" drivers.

Another approach to modification of driving styles is using BBS techniques. Although this is an approach for reinforcing safe behavior in general, it is applicable to driving style modification to the extent that it produces lasting changes in driving behavior (af Wåhlberg, 2007). The key idea behind BBS programs is to target at-risk behavior and provide later feedback to employees in several working contexts, including the automotive domain (Hickman et al., 2007; Hickman & Hanowski, 2010). In BBS programs for drivers, a video-based onboard monitoring system (OBMS) is a potentially useful tool for identifying safety-critical behaviors (Horrey, Lesch, Dainoff, Robertson, & Noy, 2012; Soccolich & Hickman, 2014). Lytx DriveCam and SmartDrive Safety are examples of drivers' feedback and coaching services provided through OBMS. Two studies of the DriveCam program, one with teen drivers (McGehee, Raby, Carney, Lee, & Reyes, 2007) and one with long-haul and short-haul carrier drivers (Hickman & Hanowski, 2011) have reported that a behavior feedback/coaching program produced a significant decrease in participants' number of safety-relevant events, showing that in-vehicle feedback and back-office feedback/coaching can modify driving behavior toward safer driving styles.

The present framework offers some concrete guidance with respect to driving style modification. A first key implication is that lasting modification of driving style necessarily involves changing drivers' values and motives. For example, a

stand-alone onboard system alerting the driver when exceeding the legal speed limit will not be expected to have any major lasting effects on driving style unless tied to incentives that motivate the driver to change his or her behavior. The same issue probably applies to training programs that are mainly instructional, that is, telling the driver what to do differently but not addressing the driver's motivation for learning and adopting a safer driving style.

Another, somewhat different, application of driving style research is the identification of who is behind the wheel (Aljaafreh, Alshabatat, & Najim Al-Din, 2012; Miyjiama et al., 2007; Wahab, Chai, Chin Keong, & Takeda, 2009; Wakita et al., 2005). Such models take advantage of the fact that habitual, automatized vehicle-control behavior (e.g., steering patterns) is often characteristic for each driver. This fact in turn could be a basis for many applications, such as providing personalized settings to the drivers, for both advanced driver assistance systems and in-vehicle information systems (Cho, Nam, & Lee, 2006; Sakaguchi, 2003; Ungoren & Peng, 2005; Xiong, Boyle, Moeckli, Dow, & Brown, 2012).

DISCUSSION AND CONCLUSIONS

As is clear from the present review, existing driving style research has generally been conducted without a common underlying framework for conceptualizing key terms and theoretical constructs. The lack of a unified conceptual framework is evidenced by the variety of existing definitions of driving styles as well as the rather arbitrary "common sense" labeling of driving style categories commonly used, which makes the results from different studies difficult to compare, synthesize, and generalize.

The present paper represents an initial attempt to synthesize findings from existing driving style research based on a novel tentative theoretical framework for understanding the concept of driving style. We define driving style broadly as "a habitual way of driving, which is characteristic for a driver or a group of drivers" and suggest that the development of driving styles may be viewed in terms of a process of habit formation driven partly by driver motives determined by individual factors, by sociocultural values and norms, and by technology. We further proposed a distinction between global and specific driving styles. Global driving styles may be viewed in terms of sets of habitual behaviors reflecting similar underlying motives (e.g., the basic motive of expediency may be reflected in speeding, close following, and a large proportion of time spent in the left lane). By contrast, specific driving styles refer to individual habitual behaviors (e.g., speeding, close following).

Existing literature addressing global and specific driving styles was reviewed, showing that there is a relatively large body of research on the topic, including both observations of actual driving behavior and self-reported data. The review also addressed the relation between self-report instruments and observed behavior and concluded that the two types of methods generally yield significantly correlated results. For speeding behavior, correlations above .60 have been reported, but for other driving styles, the magnitudes of the correlations are often relatively weak. This finding indicates a value of self-report instruments but also that caution is needed when generalizing from self-reported data to actual on-road behavior.

Moreover, several studies have shown a significant association between driving styles and different proxies for crash risk, in particular, self-reported crash involvement. The clearest finding is that crash involvement is predicted by speeding and by a high frequency of driving-related violations, which are typical characteristics of aggressive or impatient driving styles. It was suggested that the analysis of naturalistic driving data, where real crashes may be related to continuous "normal driving" data, may be a fruitful avenue for future research on the relation between driving styles and crash risk.

We also reviewed the literature on factors influencing driving styles and found evidence that driving styles are potentially determined by a variety of individual and sociocultural factors, including gender, age, driving experience, personality, cognitive style, group and organization values, and the general national/regional culture. However, further research is clearly needed to better understand more precisely how these factors shape driving style and how they may interact. The initial framework sketched out

here may serve as a starting point for framing more precise hypotheses guiding future empirical investigation on how driving styles are established.

The review also showed evidence that driving styles can be modified by various behavior-based techniques and that such modification also can contribute to reductions in crash involvement. For example, evaluation studies of courses in defensive driving (Elvik et al., 2009) have shown significant decreases in crash risk. Again, the proposed framework offers some concrete suggestions for when driving style modification would be expected to be most efficient. In particular, it emphasizes that training and behavioral feedback needs to be supported by changes in drivers' motives to have any lasting effects.

The relative importance of the various factors influencing driving style needs further investigation. For example, how strong are the effects of the Big Five personality factors compared to effects of cultural conventions of a certain region or country? Is the potential for modifying driving styles related to background factors? Conceivably, driving styles that are strongly anchored in the driver's personality may be more difficult to modify than habits formed more by sociocultural norms. Enhanced knowledge of such relationships could have implications for recruitment and training of professional drivers and for effective use of driving assistance systems.

Applications of the knowledge of driving styles are wide. Beyond driver training, driver coaching, and usage-based insurance, driving style research could also lead to the development of nonintrusive means for driver identification and to approaches for adjusting driver assistance systems to individual driving styles.

In summary, the reviewed research demonstrates the multidimensionality and complexity of the concept of driving styles. A thorough understanding of driving styles and their implications for traffic safety measures necessitates consideration of behavioral indicators and measures as well as individual background factors (like attitudes, motives, self-assessment, cognitive styles, driving experience, etc.), sociocultural factors (group/organizational values and societal norms), and technology (e.g., driving assistance functions). Our current understanding of the relationships between all these different aspects of driving styles is limited by the lack of a common theoretical model. The tentative framework suggested here could be a first step toward generating testable predictions on how driving styles are established and modified, which could then be tested in future empirical studies.

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KEY POINTS

- Driving styles and the relationships between the different aspects of driving styles are still poorly understood, largely due to the lack of a common conceptual framework.
- This paper outlines an initial framework, which was used to structure the review and potentially offers a theoretical foundation for future driving style research.
- Naturalistic driving observations represent promising approaches to future research on driving styles.
- Despite the fact that driving styles are poorly understood, there is clear evidence that some indicators, for example, related to speed and acceleration as well as a high prevalence of violations, are predictive of crash involvement risk.
- Applications of the knowledge of driving styles are wide, including behavior modification, usage-based insurance systems, and driver profiling for driver assistance systems.

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