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The association between driving anger and driving outcomes: A meta-analysis of evidence from the past twenty years

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ABSTRACT

Through the use of meta-analysis, this study investigated the relationships between driving anger and five types of driving outcomes (aggressive driving, risky driving, driving errors, near misses and accidents). The moderating effects of three variables (age, study publication year, and participants' country of origin) on these relationships were also examined. A total of 51 studies published over the past two decades met the inclusion criteria for the meta-analysis. The results showed that driving anger significantly predicted all three types of aberrant driving, with zero-order correlations of 0.312, 0.243, and 0.179 with aggressive driving, risky driving and driving errors, respectively. The correlations between driving anger and accident-related conditions, though at relatively weaker levels, were still statistically significant. Tests for effects of the moderating variables suggested that driving anger was a stronger predictor of risky driving among young drivers than among old drivers. Also, the anger–aggression association was found to decrease over time and vary across countries. The implications of the results and the directions for future research are discussed.

1. Introduction

Anger is a strong emotion associated with belligerence and negative feelings towards the cause of the anger and generally accompanied by muscular tension and arousal of the autonomic nervous system (Hambleton et al., 2004). It typically occurs in response to an actual or perceived threat, a disruption in ongoing behavior or in response to the perception of deliberate harm (Averill, 1983; Kring, 2000). Anger has been found to be more frequently experienced in the context of driving than in non-driving situations (Parkinson, 2001). A number of features of the road situation can account for this escalating anger behind the wheel. One problem can be communication between road users, which makes it difficult for a driver to accurately convey and for a target recipient to correctly interpret the message (Parkinson, 2001). Another problem is that social sanctions against anger are lower on the road due to the anonymity of the drivers behind the physical barrier provided by the vehicles (Ellison-Potter et al., 2001). In addition, situational factors such as time pressure and traffic congestion have contributed to an increased anger experiences while driving (Deffenbacher et al., 1994).

What makes driving anger a serious public problem is that in many cases, if not all cases, it can promote aberrant driving (Dahlen et al., 2005; Deffenbacher et al., 2001; Lajunen et al., 1998). Aberrant driving behaviors can contribute to road accidents, resulting in significant injuries, fatalities, and related costs (de Winter and Dodou, 2010; Iversen and Rundmo, 2002; Paleti et al., 2010). It has been estimated that aberrant driving behaviors such as speeding and running red lights accounted for approximately 56% of fatal crashes from 2003 through 2007 in the U.S. (AAA Foundation for Traffic Safety, 2009). In China, the situation is even worse, where approximately 94% of road accidents (Qu et al., 2014) and 95% of all traffic deaths (China Road Traffic Accidents Statistics (CRTAS), 2011) were associated with unsafe behaviors such as racing, tailgating, illegal overtaking and seeking confrontations with other drivers. In transportation literature (de Winter and Dodou, 2010; Richer and Bergeron, 2012), it has been theorized that aberrant driving includes at least three types of road behaviors (i.e. aggressive driving, risky driving, and driving errors) that may threaten road safety.

Although accurate and consistent definitions are lacking, it is generally accepted that both aggressive and risky driving are deliberate behaviors that may endanger the safety of both the driver and other road users. They differ in whether harmful intent towards others is involved in the behaviors. According to Lajunen et al. (1998, p. 108), aggressive driving refers to "*any form of driving behavior that is intended to injure or harm other road users*

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physically or psychologically". By this definition, behaviors such as flashing lights, honking the horn, yelling at another driver or giving obscene gestures all belong to aggressive driving category. More extreme aggressive forms, such as car ramming and physical attacks, although less common on the road, can also happen when drivers become enraged. Risky driving, by contrast, involves exclusively selfish motives such as sensation-seeking or time urgency that are not intended to harm another person (Dula and Geller, 2003; Richer and Bergeron, 2012). Typical risky driving behaviors include speeding, red light running, tailgating, frequent lane changing, racing, drunk driving, and phoning while driving (Bachoo et al., 2013; Dahlen and White, 2006; Richer and Bergeron, 2012). A variety of other behaviors such as not wearing a seatbelt, eating while driving, using a non-motor lane and so on have also been identified by previous studies as risky behaviors on the road (Dahlen et al., 2005; Lucidi et al., 2010; Sullman and Taylor, 2010). Aberrant driving also encompasses the concept of driving errors, which differ from aggressive and risky driving in that they are not deliberate deviations from safe rules and procedures, but rather are unsafe behaviors due to driver misjudgments or failures of observation. Examples of driving errors can be braking too quickly on a slippery road, failing to notice pedestrians crossing the road, or forgetting to check the rear-view mirror before making a turn.

The relationships between driving anger and aberrant driving have been widely investigated, especially after the development of the Driving Anger Scale (DAS) by Deffenbacher et al. (1994) using a sample of US drivers. The DAS was designed to measure trait driving anger, a propensity of drivers to become angry while driving. Initially, two versions, the long version containing 33 questions and the short version containing 14 questions, were proposed. In subsequent applications, some modifications were made when DAS was applied to drivers from specific countries. For example, the 21-item DAS was used for UK drivers (Lajunen et al., 1998) and the 22-item version was used for French drivers (Villieux and Delhomme, 2007). Almost all the relevant research has reported a positive correlation (expressed in terms of correlation coefficient, r) between anger and aggressive driving. However, partially due to the inconsistency in measurement scales used to assess the two terms, the strength of the identified correlations varied considerably across studies. For example, using Cohen's (1988) convention to interpret correlation coefficients as strong ($r \geq 0.5$), moderate ($0.3 \leq r < 0.5$) or weak ($r < 0.3$), Vallières et al. (2014) found a strong relationship ($r = 0.69$), Dahlen et al. (2005) reported a moderate relationship ($r = 0.42$), while Blankenship et al. (2013) only identified a weak relationship ($r = 0.25$), between driving anger and driving aggression. Similarly, the extent to which driving anger can predict risky driving is not clear cut. Both significantly positive (e.g. Oltedal and Rundmo, 2006; Sullman, 2015) and non-significant relations (e.g. Jovanović et al., 2011) have been reported in the literature. The relations between driving anger and errors have been less intensively studied and available studies suggested a positive correlation between them (Berdoulat et al., 2013; Lucidi et al., 2010; Maxwell et al., 2005).

Meta-analysis is a useful technique for combining the results of many previous relevant studies and for exploring the sources of disagreement between their results. A meta-analysis can synthesize findings from multiple studies to produce a weighted average result. By combining the results of available studies, meta-analysis has more power to detect small but significant effects (Sutton et al., 2000). In addition, the estimation of the size of an effect can be improved because when compared with individual studies, meta-analysis is based on much more information extracted from the results of many studies (Borenstein et al., 2011; Zhang and Chan, 2014).

One previous meta-analysis of driving anger and aggressive driving was conducted by Nesbit et al. (2007) by reviewing 18 articles published from 1994 to 2004. The results of the meta-analysis revealed an average correlation of 0.37 between driving anger and aggressive driving, suggesting that these two were moderately and positively associated. However, not all the 18 reviewed studies were concerned specifically with driving anger. Some measured other constructs such as driver stress (e.g. Matthews et al., 1997) or attitude towards driving violations (e.g. Underwood et al., 1997), and therefore, including them in the meta-analysis may have been confounded with the effects of driving anger. Also, significant heterogeneity in the anger–aggression correlation was identified in that study. Nesbit et al. (2007) examined the reasons for the heterogeneity and indicated that the wide variety of the aggression measurement methods (self-report questionnaire, driving log, or driving simulator) partially accounted for it. Unfortunately, additional sources for the heterogeneity were not further investigated in that study. Given that in Nesbit's study, risky driving behaviors such as running a red light were also counted as aggressive driving, it is highly possible that the combination of different types of aberrant driving behaviors contributed to the heterogeneity. Another limitation of this earlier meta-analysis work was that the issue of publication bias was not addressed. Publication bias refers to the phenomenon that research findings are less likely to be published when they are not statistically significant, they are against the previously published materials, or are hard to explain. Publication bias in the study by Nesbit et al. (2007) might have resulted in an upwardly biased estimate of the anger–aggressive driving relationship. Therefore, for more accurate estimates, there is a need to conduct further studies using meta-analysis that only reviews studies focused on driving anger. Moreover, the meta-analysis should be performed for each driving outcome, and be adjusted for publication bias.

There has been great interest in research into driving anger since the work of Nesbit et al. (2007), providing an adequate foundation for further quantitative review of its adverse effects on driving. In addition to a more precise estimation on the size of the effect of driving anger, a large number of available studies also offer an opportunity for a thorough examination of potential moderators. For example, the greater time span covered by the available studies since the previous meta-analysis work makes it possible now to investigate how the anger–aggression correlation changes over time. Such analysis can serve to inform researchers and policy makers about whether intervention strategies aimed at reducing the adverse effects of driving anger are effective or not. Moreover, by testing how personal factors, such as age and gender, can moderate the associations, it is now possible to explore whether the impact of driving anger would reveal individual differences. Identification of the driver group or groups that are most severely affected by driving anger, would allow intervention strategies to be aimed initially at these drivers.

Many studies on driving anger and its impact on driving have been conducted in the twenty years following the development of DAS, yet, a synthesis of the available results is still lacking. This study aimed to perform a quantitative review of the effects of driving anger on different types of driving outcomes using the meta-analysis technique. It should be noted that this review focused exclusively on driving anger. Apart from the frequently studied trait driving anger, which is the tendency of drivers to become angry while driving, studies on situational (state) driving anger, which is a current temporary level of anger experienced during driving as opposed to the more continuous trait anger, were also examined for this review. However, research that only explored the effect of general anger on driving was excluded. This was because, although driving anger and general anger are moderately correlated, they are fairly independent anger constructs and have different impacts on driving (Deffenbacher et al., 2001, 2002). Five types of driving outcomes, including three aberrant driving

behaviors (aggressive driving, risky driving, and driving errors) and two accident-related conditions (near-misses and accidents), were separately subjected to meta-analysis.

Furthermore, the moderating effects of three variables (age, study publication year, and participant country of origin) were investigated. Older adults have been found to be less likely to express anger outwardly via verbal or physical aggressive behaviours compared with their younger counterparts (Phillips et al., 2006). The age difference remained even after partialling out levels of anger. Therefore, it is hypothesized that the associations between driving anger and all types of adverse driving outcome would decrease with driver age (Hypothesis 1). With respect to study publication year, considering that traffic congestion may promote aggressive expressions of anger behind the wheel (Wickens et al., 2013) and it is increasing worldwide (Traffic Scorecard Annual Report, 2014), it is hypothesized that the identified association between driving anger and driving aggression would be greater in the more recently conducted studies (Hypothesis 2). The effects of driving anger may vary across countries since attitude and tolerance towards anger and aggression is closely related to culture. Given that the culture in Asian countries typically disapproves of extreme emotional expression (Maxwell et al., 2009), it is hypothesized that anger–aggression correlation would be lower in Asian countries than in Western countries (Hypothesis 3).

2. Methods

2.1. Literature search

A literature search was conducted to recover published and unpublished studies that have investigated the associations between driving anger and driving outcomes. All types of scientific studies, including journal articles, papers presented at scientific conferences, book chapters, reports, PhD dissertations, and Bachelor or Master theses, were candidates for this review. The search was conducted with Google Scholar using the following keywords and Boolean connectors: driving AND (anger OR irritation OR rage) AND (behavior OR near miss OR accident OR crash). The abstract of each article was examined and only articles written in English and related to driving situations were kept for further investigation. At this initial search stage; a total of 233 articles were collected.

Next, a thorough reading of the retrieved articles was conducted and only those satisfying the following criteria were retained for meta-analysis. First, appropriate measures must have been used for assessing driving related anger (either trait-based or situational-based). A number of methods, such as the DAS or other self-designed scales, can be used for this purpose. Some articles did not record driving anger, but measured constructs (e.g. general anger or hostility) or states (e.g. anxiousness) that were related to driving anger. These studies were not included in the meta-analysis as these terms were not the same as driving anger and their effects on driving outcomes can be quite different from driving anger. Second, in the eligible studies, the types of aberrant driving measured should either be clearly stated or easily inferred from the situations reported. Studies that made no distinction between different types of aberrant driving behaviors were excluded. An example of valid measures of aggressive driving can be seen in the aggressive violation subscale from Driver Behavior Questionnaire (DBQ, Rimmö and Åberg, 1999). An example of valid measures of risky driving is the ordinary violation subscale of the DBQ. For driving errors, an example of valid measures is the error subscale (sometimes named as lapses or slips) from the DBQ. The third selection criterion was that studies must have examined the relations between driving anger and driving outcomes. Furthermore, the relations must be reported in any of the following forms of zero-order effect sizes: correlation, means and SD, *t*-statistics, *F*-statistics between two groups, or odds ratios. For studies reporting effect sizes from multivariate analysis (typically the standardized regression coefficients or path coefficients), they were also reviewed, but separately analyzed from the zero-order effects. A total of 51 studies satisfied these criteria and were meta-analyzed in this study.

2.2. Coding procedures

Research studies that met the above-mentioned inclusion criteria were coded on several aspects. In terms of the characteristics of the participants, the following four categories of information were extracted and used when available: sample size, proportion of male and female participants, average age, and average driving experience. If the mean age was not reported, it was estimated based on the available data (typically from the frequency counts of stratified-by-age groups). The country of origin of the participants was then extracted. Driving anger was coded as either situational mode (S) or trait mode (T) and its measurement was coded as DAS or others (e.g. self-designed questionnaire). The driving outcomes were coded into five categories: (1) aggressive driving (AD); (2) risky driving (RD); (3) driving errors (DE); (4) near misses (NM), and (5) accidents (AC). Examples of the three types of aberrant driving can be found in the above paragraph. For near misses, they were considered as driving incidents where no property was damaged and no person was injured in this research. For accidents, different types such as minor accidents, major accidents, property-damaged accidents and human-injury accidents have been reported in the included studies. In this review, no distinction was made between them and they were all coded as accidents.

The relationships between driving anger and driving outcomes were extracted from each of the retained study. The majority of the reviewed studies reported the correlation coefficient and therefore it was chosen as the standardized effect size metric here. Other types of effect sizes (e.g. *t*-statistics) were converted into correlations by using methods introduced by Borenstein et al. (2011). The correlations obtained were coded as either zero-order effects (Z) or effects from multivariate analysis (M). The effect size generated through multivariate technique reflects the influence of all predictor variables in a multivariate model, which can be quite different from the zero-order effect between two variables. As a result, the two types of correlations were separately meta-analyzed.

In some studies, more than one correlation between driving anger and one type of driving outcome were reported. For example, in the study of Dahlen et al. (2005), the effects of driving anger on physical and verbal aggression were separately reported ($r = 0.25$ and 0.50, respectively). In these cases, the average of the available correlations between driving anger and the same type of driving outcome ($r = 0.38$ for the above example) was noted down. This is a common practice to deal with the many effect sizes of the same category reported in one study (de Winter and Dodou, 2010; Nesbit et al., 2007). Two of the reviewed studies (Dahlen et al., 2005; Sullman, 2006) indicated non-significant associations between driving anger and accidents, but did not offer any statistical details (i.e. the specific correlation coefficients). Previous meta-analysis reviews dealt with such situations by discarding the unreported non-significant effect size, with the risk of generating larger average effects than would otherwise be the case. A way of eliminating such an upward bias is to assign a zero effect size to the non-significant impact (Caird et al., 2008) and this was the method used in this review.

2.3. Meta-analysis method

The meta-analysis was conducted according to driving outcome type (aggressive driving, risky driving, driving errors, near

misses, and accidents) and correlation type (zero-order and multivariate). Two statistical models, the fixed-effects model and the random-effects model, are commonly used in meta-analysis. The fixed-effects model assumes that there is one true effect size which underlies all the studies in the analysis while the random-effects model assumes that the true effect could vary from study to study. In this analysis, the fixed-effects model was used since it was assumed that the effect of driving anger on one type of driving outcome should be the same for all studies. The validity of such an assumption was tested (i.e. heterogeneity test) based on the I^2 statistic proposed by Higgins and Thompson (2002). In case of the existence of heterogeneity (i.e. $I^2 > 75\%$), the sources of heterogeneity (i.e. age, study publication year, participant origin) was investigated using meta-regression or subgroup analysis.

In this review, the trim-and-fill analysis was used to test and adjust for the possible presence of publication bias when at least five estimates of effect sizes (i.e. five correlation coefficients) were available for one meta-analysis (Duval and Tweedie, 2000). The trim-and-fill technique is based on the assumption that in the absence of publication bias, the data points in a funnel plot, which is a scatter plot of effect size against the study sample size, should be symmetrically distributed around the estimate. The technique detects publication bias by testing for asymmetry in the funnel plot. In case of publication bias, three steps are performed to adjust for the bias. First, data points causing the asymmetry are removed. Then, the "center" of the funnel plot (i.e. weighted average effect size) is re-estimated using the retained studies. Third, previously removed studies are restored and at the same time new data are added to make the "center" generated in the second step remain unchanged. For detailed technical description of how to perform a trim-and-fill, interested readers can refer to Borenstein et al. (2011).

3. Results

3.1. Main characteristics of included studies

A total of 51 studies were included for the meta-analysis of the correlations between driving anger and various types of driving outcome. Nine of these 51 studies were also used in the previous meta-analysis study by Nesbit et al. (2007). A complete list of the studies included here can be found in Appendix A. Of these studies, 27.5% were published in the first ten years after the development of DAS in 1994 and the other 72.5% were published within the second decade, indicating that research attention paid to driving anger has increased in recent years. The majority of the research (45 out of 51, 88.2%) involved a questionnaire-based survey. Of the 6 studies not based on the questionnaire method, 5 used driving simulator experiments and one used a field experiment to collect driving data. The sample size varied greatly across studies, with the largest recruiting 2605 participants (Iversen and Rundmo, 2002) and the smallest recruiting only 15 participants (Abdu et al., 2012).

Table 1
Summary of characteristics of the included studies.

Characteristics	Proportion
Publication time	
1995–2004	27.5%
2005–2015	72.5%
Method	
Questionnaire	88.2%
Simulator	9.8%
Field	2.0%
Average age of participants	
<=20	28.8%
20–30	30.8%
30–40	21.2%
40–50	15.4%
Unreported	3.8%
College students	
Yes	47.1%
No	52.9%
Origin	
Western countries	94.1%
Other	5.9%

Surprisingly, nearly half (47.1%) of the included studies had used only college students in their samples and as a result the average age of participants in these studies was around 20 years (see Appendix A). For the 52.9% studies that did not use college student samples, the average age of participants was usually more than 30 years, with participants in the study by Sullman (2015) being the oldest (mean = 49.0 years). Except for two studies that recruited only male participants (Abdu et al., 2012; Sullman et al., 2013) and two that reported no gender proportion (Nesbit and Conger, 2012; Ward et al., 1998), all other studies contained approximately equal proportion of male and female participants in their samples. Almost all studies (48 out of 51, 94.1%) were carried out in western countries. The three exceptions have focused on driving anger problems in Israel (Abdu et al., 2012), China (Li et al., 2014) and Malaysia (Sullman et al., 2014). Only three of the reviewed studies investigated situational driving anger, the rest focused only on trait driving anger. Characteristics of the reviewed studies are summarized in Table 1.

3.2. Zero-order effects of driving anger on driving outcomes

As mentioned earlier, the analysis was conducted according to driving outcome type (aggressive driving, risky driving, errors, near misses, and accidents) and correlation type (zero-order and multivariate). The generated average zero-order correlations and their 95% confidence interval (CI) are summarized in Table 2. The results show that driving anger was positively correlated with all five types

Table 2
Results of meta-analysis on the zero-order correlations between driving anger and driving outcomes.

Driving outcome	Number of studies	Total sample size	Initial analysis results			Adjustment for publication bias			
			Overall *r*	95% low	95% high	Data point added	Overall *r*	95% low	95% low
Aggressive driving									
Overall	35	10,002	0.348	0.330	0.365	8	0.312	0.295	0.328
DAS	29	8762	0.323	0.394	0.341	6	0.300	0.282	0.318
Risky driving									
Overall	25	10,280	0.243	0.225	0.261	0	0.243	0.225	0.261
DAS	24	10,265	0.243	0.224	0.261	0	0.243	0.224	0.261
Driving errors	3	880	0.179	0.114	0.242	N/A	0.179	0.114	0.242
Near misses	7	2252	0.161	0.121	0.201	2	0.138	0.101	0.175
Accidents	17	9349	0.033	0.012	0.053	1	0.032	0.012	0.052

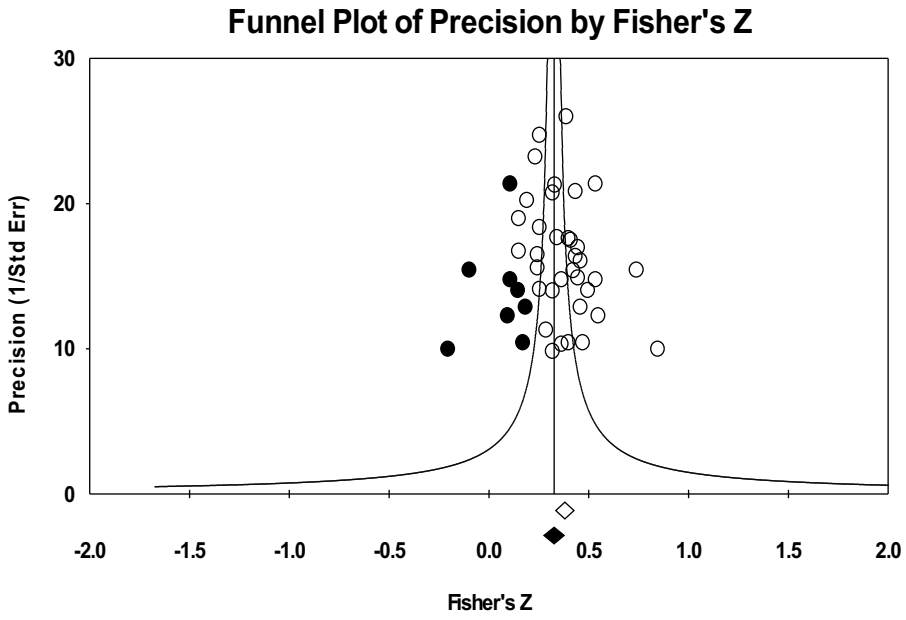

Fig. 1. Funnel plot of anger–aggression correlation adjusted for publication bias. Solid circles are the original data; open circles are the newly added data.

of driving outcome. For the three categories of aberrant driving behaviors, driving anger showed highest correlation with aggressive driving ($r = 0.348$), followed by risky driving ($r = 0.243$) and then driving errors ($r = 0.179$). The correlations between driving anger and accident-related outcomes were smaller than on behavior-related outcomes, showing a 0.161 correlation with near misses and a 0.033 correlation with accidents. All the five r values calculated had a significance level of 0.05 or less. To minimize the noise, additional meta-analysis was conducted on anger–aggression and anger-risky driving correlations by limiting studies that used DAS to measure trait driving anger (see Table 2). The anger–aggression correlation decreased to 0.323 after omitting the six studies that did not use DAS. The anger-risky driving correlation stayed at the same level (0.243).

The potential presence of publication bias in the meta-analysis of aggressive driving was first examined using the trim-and-fill analysis (Duval and Tweedie, 2000). The results revealed a presence of publication bias and in order to adjust for it, 8 new data points were added into the funnel plot (Fig. 1). After adjusting for publication bias, the re-estimated average correlation between driving anger and aggressive driving was 0.312 (95% CI: 0.295–0.328). Similar methods on detecting and adjusting for publication bias were performed for the meta-analysis of risky driving, near misses and accidents. No evidence of publication bias in risky driving analysis was found. However, there was publication bias in near misses and accidents meta-analysis and two and one new data points were added respectively to adjust for the bias. The adjusted correlation between driving anger and near misses decreased to 0.138 (95% CI: 0.101–0.175) while the anger-accidents correlation remained at a similar level (0.032, 95% CI: 0.012–0.052) after the adjustment for publication bias. Summary of these adjustments can be found in the last four columns in Table 2. The estimate of anger–errors correlation was not tested for publication bias since it did not satisfy the minimum study number requirement, which is 5 for trim-and-fill analysis (Duval and Tweedie, 2000).

Next, the potential heterogeneity problems were tested using the I^2 statistic. The I^2 statistic values for meta-analysis on aggressive driving, risky driving, errors, near misses and accidents were 80.50%, 79.13%, 0.00%, 61.48%, and 34.12%, respectively. Based on the 75% cut-off value (Higgins and Thompson, 2002), the heterogeneity was a problem in aggressive and risky driving analysis but not in other three analyses. To explore the possible sources of the heterogeneity, the moderating effects of the three variables (age, study publication year, country of origin) on the above relationships were examined in order to give insight into the specific effects of driving anger for particular populations and individuals.

3.3. Age, publication year, and origin as moderators

The moderating effects were investigated using meta-regression analysis for age and publication year, and subgroup analysis for country of origin. With respect to the anger–aggression correlation, one study (Ward et al., 1998) was excluded from the moderating analysis for not reporting the average age of the participants. The meta-regression results showed that the effect of age was not significant (unstandardized regression coefficient or b, $=-1.67 \times 10^{-3}$, $p = 0.094$). Publication year was found to be a significantly negative predictor for the anger–aggression correlation ($b = -4.3 \times 10^{-3}$, $p < 0.05$) and its effect is graphically illustrated in Fig. 2. It may be seen that the anger–aggression correlation decreased with publication year, a result which did not support Hypothesis 2 that the association between driving anger and driving aggression would be greater in the more recent studies.

To test whether country of origin can be a moderator for the anger–aggression correlation, the effect sizes were classified into four subgroups (one study from South Africa was disregarded in this analysis): North America (18 studies: 16 from the U.S. and 2 from Canada), Europe (12 studies), Australia (2 studies), and Asia (2 studies). The subgroup analysis indicated that the effect of origin was significant ($p < 0.001$). The anger–aggression correlation was highest in North America ($r = 0.421$; 95% CI: 0.395–0.447), followed by Australia ($r = 0.399$; 95% CI: 0.343–0.453), then Europe ($r = 0.300$; 95% CI: 0.271–0.327), and lowest in Asia ($r = 0.215$; 95% CI = 0.145–0.285). Post-hoc pairwise comparisons indicated that except for the difference between Australia and Europe ($p = 0.44$), the differences between each two subgroups were significant and therefore Hypothesis 3, that anger–aggression correlation would be lower in Asian countries than in Western countries, was supported.

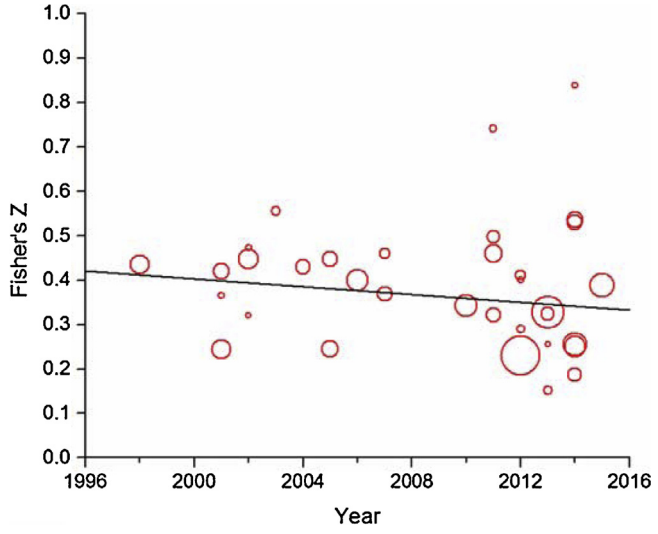

Fig. 2. Meta-regression analysis on the effect of publication year on the anger–aggression correlation. The area of the dots corresponds to the sample size. The straight line (b: -4.47×10^{-3}; interception: 9.34) represents the best linear fit to the data. Note: the longitudinal coordinate represents the Fisher's Z rather than the correlation. This is because in meta-regression, the correlation is converted to the Fisher's Z scale first and the regression is performed using the transformed values.

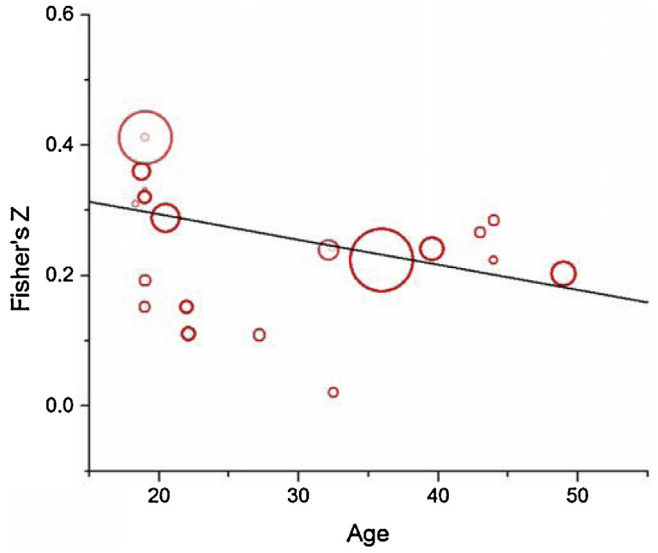

Fig. 3. Meta-regression analysis on the effect of age on the anger-risky driving correlation. The area of the dots corresponds to the sample size. The straight line (b: -3.87×10^{-3}; interception: 0.371) represents the best linear fit to the data. Noted: the longitudinal coordinate represents the Fisher's Z scale rather than the correlation coefficient *r*.

Two studies not reporting the average age of the participants (Ellison-Potter et al., 2001; Ward et al., 1998) were excluded from the meta-regression analysis of the effect of age on the anger-risky driving correlation. The results (see Fig. 3) showed that the strength of the correlation decreased significantly with age ($b = -3.87 \times 10^{-3}$; $p < 0.001$). That is, driving anger showed a stronger relationship with risky driving among young drivers than that among elderly drivers. The publication year, on the other hand, did not significantly moderate the anger-risky driving correlation ($b = -1.85 \times 10^{-3}$; $p = 0.347$). Similar to the previous analysis, the reviewed studies were classified into four groups based on the origin of the survey samples: North America (10 studies), Europe (11 studies), Australia (2 studies), and Asia (1 study). The subgroup analysis failed to reveal a significant effect of country of origin (North America: 0.239, Europe: 0.205, Australia: 0.205, Asia: 0.492; $p = 0.304$).

Finally, whether the anger-accidents correlation varied with age, publication year and country of origin was tested. The results showed that the effect of age ($b = 1.91 \times 10^{-3}$; $p = 0.080$), publication year ($b = 1.90 \times 10^{-3}$; $p = 0.461$) and country of origin ($p = 0.219$) were not significant. Due to the limited number of available studies, the moderating effects of the three variables on anger-near misses and anger-errors correlations were not investigated.

3.4. Multivariate effects of driving anger on driving outcomes

Some researchers have suggested not using effect sizes generated from multivariate technique (e.g. standardized coefficients from regression analysis) in meta-analysis (e.g. Hunter and Schmidt, 2004). The reason is simply that the predictors in multivariate models usually vary across studies, resulting in effect sizes that are not technically comparable to each other. Despite such concerns, the effect sizes from multivariate analysis, which can be termed multiple correlations here, were still meta-analyzed in this review. Given the lack of control on other predictors in the multivariate model, such analysis would not aim to provide definitive conclusions, but to suggest a direction for additional research. It should be noted that the anger-errors multiple correlations were not meta-analyzed since no studies were available. The corresponding meta-analysis results are summarized in Table 3. The four average correlations were all positive and significant.

4. Discussion

The purpose of this study was to synthesize a section of the literature on driving anger using the meta-analysis technique. By integrating the results over the past twenty years, estimates of the correlations between driving anger and different driving outcomes have been determined.

Among the five types of driving outcomes investigated, aggressive driving was most strongly related to driving anger. A popular explanation for such a correlation can be the frustration–aggression hypothesis (Dollard et al., 1939). According to this view, failure to reach a certain desired goal due to circumstance or other people often causes anger or frustration, which in turn leads to aggression and expressions of anger towards other road users and/or towards the circumstances causing hindrance. In traffic settings, the two main goals of drivers are to achieve a destination on time (arrival goal) and to drive safely (safety goal) (Roidl et al., 2013a). When these goals are blocked (e.g. due to traffic congestion or dangerous behavior from other drivers), anger or frustration is very likely to be experienced, which can further lead to aggressive behaviors (e.g. continuously sounding the horn or purposely blocking other drivers). Moreover, compared with non-driving situations people are more likely to express anger outwardly and aggressively in the context of driving since the target of the anger and aggression are usually other road users, and due to the shell like structure of the car, there is anonymity on both sides (Lawton and Nutter, 2002). The combination of such factors results in a significant association between aggressive driving and the experience of anger behind the wheel. However, the association is only moderate, which may be because, apart from anger, other factors such as impatience or seeing aggressive driving by other drivers can also account for aggression (Shinar, 1998).

Recent research has demonstrated that a range of human cognitive performance, including attention allocation, reasoning, judgment, and decision making, can be impaired by anger (for a review, see Blanchette and Richards, 2010). In particular, angry

Table 3
Results of meta-analysis on the multiple correlations between driving anger and driving outcomes.

Driving outcome	Number of studies	Total sample size	Initial analysis results		
			Overall *r*	95% low	95% high
Aggressive driving	14	4422	0.319	0.292	0.346
Risky driving	13	9467	0.221	0.202	0.240
Near misses	3	749	0.184	0.114	0.253
Accidents	4	3449	0.074	0.040	0.107

individuals tend to perceive a lower level of risk while at the same time show a more favorable attitude towards taking risks (Lerner and Keltner, 2001; Taubman-Ben-Ari, 2012), which combined may explain the positive correlation between driving anger and risky driving identified here. Three studies have investigated the anger-errors association and the meta-analysis results here supported a positive relationship between driving anger and driving errors. One possible explanation for this positive correlation may be the wandering mind or off-task thinking associated with negative emotions such as anger. For example, Smallwood et al. (2009) found that when negative emotions were induced in participants, they made more errors and reported a greater frequency of task irrelevant thoughts, and also a decreased ability to adjust performance after an error. However, it is unclear whether such relationships would still hold true in driving situations. Alternatively, it is possible that the positive anger-errors correlation was a result of tunnel vision (a constricted tunnel-like field of vision) associated with anger (Friedman and Förster, 2010). There is evidence that angry drivers scan a narrowed area, which can increase the risk of failing-to-see potential traffic hazards in time and consequently commit errors. To sum up, whereas the effects of driving anger identified in this study seem to be supported by available theories and previous findings, future direct evidence is required for more in-depth understanding of the working mechanism of driving anger.

For the possible association between driving anger and an increased in the risk of accident involvement, some studies have failed to find any significant correlation between them and concluded that driving anger does not necessarily increase accident risk (Dahlen et al., 2005; Deffenbacher et al., 2005; Lonczak et al., 2007). If this is the case, then the occurrence of driving anger should not cause casualties or property losses and therefore treatment programs on driving anger would seem to be of little practical value, except of course that there will be an effect on other road users. In contrast, other researchers have found that drivers admitting to having more anger while driving also tended to have higher accident records (Deffenbacher et al., 2003b; Delhomme et al. 2012). As a result, they emphasized the need to develop interventions to reduce the adverse consequence of driving anger. The meta-analysis here aimed to reconcile this discrepancy by synthesizing available evidence and the result was that driving anger was found to be associated with increased risk of accident involvement. The anger-accidents correlation found here was positive and statistically significant. Although the correlation was weak, it does indicate a higher accident risk for drivers who are prone to experience anger while driving. The finding here that driving anger could be a potential threat to public safety serves as a good foundation to support policy makers in the development and promotion of driving anger treatment strategies.

This study has identified several important moderating effects. Driving anger was a stronger predictor of risky driving among young drivers than among old drivers. This is consistent with previous findings that older adults were better at anger regulation than their younger counterparts (Phillips et al., 2006). In a traffic setting, it has also been shown that younger drivers usually coped with frustration in aggressive and risky ways while older drivers commonly tried to get rid of frustration by adjusting their goals or lowering their expectations (Lajunen et al., 1998; Shinar, 1998). What makes the situation more severe for young drivers is that they are more frequently and intensively anger provoked while driving (Li et al., 2014; Sullman et al., 2007). Overall, driving anger is a more serious problem for young drivers and this is the driver group to which future research and public policy should attend.

Although it was expected that the anger–aggression correlation would become stronger in more recent years given the increasing traffic congestion problem worldwide, this hypothesis was not supported by the evidence in this review. The meta-regression result here showed a statistically significant tendency for this correlation to decrease over time. It is possible that this result may be attributed to the implementation of strong laws and some successful intervention programs aimed at reducing aggressive driving behaviors (Kazemeini et al., 2013; Zhang et al. 2010). With respect to anger-risk driving and anger-accidents relationships, the meta-regression results failed to reveal any significant moderating effects of publication year, which indicated the generally consistent correlations between driving anger and the two types of driving outcomes. Based on this result, it is suggested that the effectiveness of interventions (e.g. driver education, publicized enforcement or legislation) to reduce risky driving problem should be reconsidered. Finally, the hypothesis that anger–aggression correlation was smaller in Asian countries was supported. Yet, given the limited number of studies reviewed from Asia, this result should be interpreted with caution.

As recommended by de Winter and Dodou (2010), the effect sizes from multivariate analysis were meta-analyzed in this study. Compared with zero-order correlations, the predictor power of driving anger on aggressive and risky driving became smaller in multivariate analysis, which can be explained by the fact that in multivariate analysis, the effects of other important predictors, such as age and gender, were ruled out. What was really surprising was the finding that the influence of driving anger on near-misses and accidents became stronger in multivariate analysis (*r* increased from 0.140 to 0.186 for near misses and from 0.033 to 0.056 for accidents). A possible explanation for such an unexpected finding is the limited number of studies used in these meta-analyses, which may have compromised the result.

Several limitations in this meta-analysis study should be addressed. First, no causal inferences can be made from the results of this study. The significant correlations between driving anger and different driving outcomes identified here do not imply the causal effects of driving anger. Second, the anger-error correlation was derived from a small sample size and therefore should be interpreted with caution. Third, a variety of measurement tools have been used in the reviewed studies to assess driving outcomes. Whether the relationships would vary depending on the mode of measurement was not investigated here. Fourth, gender and mileage (exposure) are important demographic variables that may moderate the associations between anger and driving outcomes. Unfortunately, most of the reviewed studies did not report the associations for male and female drivers separately or include the driving mileage information, making it impossible to test the moderating effect of gender and mileage.

5. Future research

The results here showed that increasing research attention is being paid to driving anger, as reflected by the relatively large number of studies published in the past ten years. However, additional research is required on the following areas to provide a more comprehensive understanding of driving anger and to assist in the development of intervention strategies to eliminate the adverse effects of driving anger. First, studies using more representative samples of the general driver populations as well as more specific driver groups are required. The recruited participants in the majority of available studies were generally young and novice drivers, probably because this group of drivers is a high risk segment of the population. However, these results may not be generated to the general public and therefore studies with more representative samples are needed. Moreover, studies focused on specific driver groups, such as the elderly or professional drivers, will also contribute to a more detailed understanding of driving anger. Second, the majority of reviewed studies in the field of driving anger have been concerned with drivers in the U.S. and in European countries. Although the severity of road rage is increasing in eastern countries, the problem has not yet been given much attention. It seems very likely that, due to the many variations in culture, politics, and society between Asia, Europe and America, driving anger and its effects are likely to vary across these different areas and cultures. Third, the accidents reported in the studies in this meta-analysis are self-reported based. To build evaluation of the effects of driving anger, future studies should consider using more objective measures (e.g. police report or insurance record) of traffic accidents. Finally, the effect of situational driving anger on road safety should be addressed in future studies. Much of the research so far has focused on the personal trait characteristics of drivers and how these contribute to predispose drivers to engage in aggressive behavior. Future studies focusing on state driving anger are needed for a deeper understanding on the mechanism of anger.

6. Conclusions

Driving anger has received increasing research attention over the past two decades; yet, up to the present there has been no quantitative literature review of its relationships with driving outcomes. The study reported here aimed to partially fill this gap in research by examining and synthesizing the relationships in the literature between anger and different types of driving outcomes. Results from the meta-analysis indicated that aggressive driving, risky driving, and driving errors, were all positively related to driving anger. In addition, a higher road accident risk was found to be related to driving anger and young drivers were found to be more susceptible to the adverse effects of driving anger. These quantitative estimates should be of help to researchers and policy makers who are seeking specific data about the relationships between driving anger and driving outcomes. To the extent that driving anger was and remains significantly associated with accident risk, it continues to pose a serious threat to public safety. Therefore treatment programs and intervention strategies to reduce driving anger are needed. This research also underlines the need for more research attention to be given to specific driver groups such as elderly drivers, professional drivers and to drivers in Asian countries.

Appendix A.

Summary of studies included in meta-analysis.

No.	Study	Participants	Origin	Method	Driving anger	Anger type	*r* type	Driving outcome	*r*
1	Lajunen et al. (1998)*	270 (165 M; 98 F); A = 44; E = UR	UK	Q	21 DAS	T	Z	AD	0.41
						T	Z	RD	0.28
2	Ward et al. (1998)*	362; A = UR; E = UR;	UK	Q	14 DAS	T	Z	AD	0.15
						T	Z	RD	0.18
3	Underwood et al. (1999)*	100 (48 M, 52 F); A = 23; E = 3	UK	F	33 DAS & O	S	Z	NM	0.24
4	Deffenbacher et al. (2001)*	274 (117 M, 157 F); A = 19; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.24
						T	Z	RD	0.15
						T	Z	AC	−0.03
5	Ellison-Potter et al. (2001)	289 (133 M, 156 F); A = UR; E = UR; CSO	U.S.	S	14 DAS	T	Z	RD	−0.05
						T	Z	AC	0.03
6	Knee et al. (2001)*	109 (39 M, 70 F); A = 22.08; E = UR; CSO	U.S.	Q	33 DAS	T	Z	AD	0.35
						T	Z	AC	0.09
7	Lajunen and Parker (2001)	239 (190 M, 98 F; 1 NR); A = 44; E = UR	UK	Q	21 DAS	T	Z	AD	0.40
8	Deffenbacher et al. (2002)*	290 (82 M, 182 F, 26 UR) A = 19; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.42
						T	Z	RD	0.19
						T	Z	NM	−0.01
						T	Z	AC	−0.06
						T	M	AD	0.02
						T	M	RD	0.01
9	Iversen and Rundmo (2002)	2605 (1250 M, 1355 F); A = 45; E = 23	Norway	Q	14 DAS	T	M	RD	0.25
						T	M	AC	0.09
10	Neighbors et al. (2002)*	111 (28 M, 83 F), A = 23.6; E = UR; CSO	U.S.	Q	O	T	Z	AD	0.44
						T	M	AD	0.63
11	Schreer (2002)*	99 (31 M, 68 F), A = 20.7; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.31
12	Deffenbacher et al. (2003a)	97 (43 M, 54 F), A = 19; E = UR;STD	U.S.	S	14 DAS	T	Z	RD	0.32
13	Deffenbacher et al. (2003b)	153 (91 M, 62 F), A = 19; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.50
						T	Z	RD	0.30
						T	Z	AC	0.27
14	Deffenbacher et al. (2004)*	436 (218 M, 218 F) A = 18.75; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.41
						T	Z	RD	0.35
						T	Z	NM	0.21
						T	Z	AC	0.08

						T	M	AD	0.41
						T	M	RD	0.33
15	Dahlen et al. (2005)	224 (67 M, 157 F) A = 19; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.42
						T	Z	RD	0.39
						T	Z	NM	0.26
						T	M	AD	0.41
						T	M	RD	0.32
						T	M	NM	0.21
						T	M	AC	0.00
16	Maxwell et al. (2005)	245 (114 M, 113 F) A = 32.44; E = UR	UK	Q	21 DAS	T	Z	AD	0.24
						T	Z	RD	0.24
						T	Z	DE	0.16
17	Dahlen and White (2006)	312 (90 M, 222 F); A = 19; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.38
						T	Z	RD	0.31
						T	Z	NM	0.18
						T	Z	AC	0.03
						T	M	RD	0.26
						T	M	AD	0.31
						T	M	NM	0.12
						T	M	AC	−0.02
18	Oltedal and Rundmo (2006)	1356 (632 M, 724 F); A = 19; *E* = UR; CSO	Norway	Q	14 DAS	T	Z	RD	0.39
						T	Z	AC	0.04
						T	M	RD	0.24
19	Sullman (2006)	861 (481 M, 372 F; 8 UR); A = 39.3; E = 21.9	New Zealand	Q	33 DAS	T	Z	AC	0.00
20	Van Rooy et al. (2006)	322 (85 M, 237 F) A = 22.12; E = UR; CSO	U.S.	Q	14 DAS	T	Z	RD	0.11
21	Eşiyok et al. (2007)	220 (110 M, 110 F) A = 36.96; E = 10.13	Turkey	Q	33 DAS	T	Z	AD	0.35
						T	M	AD	0.16
22	Lonczak et al. (2007)	1217 (785 M, 432 F); A = 32.2; E = UR	U.S.	Q	33 DAS	T	Z	AC	−0.02
23	Millar (2007)	168 (71 M, 97 F); A = 20; E = UR; CSO	U.S.	Q	14 DAS	T	Z	AD	0.43
24	Björklund (2008)	98 (51 M, 47 F); A = 35; E = 16	Sweden	Q	21 DAS	T	M	AD	0.47
25	Fernandes et al. (2010)	215 (92 M, 123 F); A = 19; E = UR; CSO	Australia	Q	14 DAS	T	M	RD	0.20
26	Lucidi et al. (2010)	180 (102 M, 78 F); A = 18.33; E = 0.62; CSO	Italy	Q	14 DAS	T	Z	RD	0.30
						T	Z	DE	0.20
27	Villieux and Delhomme (2010)	314 (170 M, 144 F); A = 22; E = 3.1; CSO	France	Q	22 DAS	T	Z	AD	0.33
						T	Z	RD	0.15
						T	M	AD	0.14
						T	M	RD	0.03

28	Herrero-Fernández (2011)	432 (135 M, 297 F); A = 22; E = 3; CSO	Spain	Q	14 DAS	T	Z	AD	0.31
29	Jovanović et al. (2011)	260 (137 M, 123 F);	Serbia	Q	21 DAS	T	Z	AD	0.43
		A = 32.5; E = UR				T	Z	RD	0.02
						T	Z	AC	0.01
						T	M	AD	0.37
30	Wickens et al. (2011)	Study 1: 240 (64 M, 152 F); A = 22.10; E = 5.06	U.S.	Q	O	T	Z	AD	0.63
		Study 2: 199 (58 M, 141 F); A = 23.24; E = 6.04				T	Z	AD	0.46
31	Abdu et al. (2012)	15 (15 M, 0 F); A = 24.5.	Israel	S	O	T	Z	RD	0.49
		E = 6.5; CSO				T	Z	AC	0.27
32	Dahlen et al. (2012)	308 (129 M, 178 F; 1	U.S.	Q	14 DAS	T	Z	AD	0.39
		UR); A = 37.89;				T	Z	AC	0.10
		E = 21.08				T	M	AD	0.32
						T	M	AC	0.08
33	Delhomme et al. (2012)	2038 (1060 M, 978 F);	France	Q	33 DAS	T	Z	AC	0.07
		A = 23.2; E = 4.2				T	M	RD	0.11
34	González-Iglesias et al. (2012)	541 (249 M, 292 F);	Spain	Q	22 DAS	T	Z	AD	0.23
		A = 39.56; E = 18.92				T	Z	RD	0.24
						T	Z	AC	0.03
			(A;E;G)			T	M	RD	0.02
35	Nesbit and Conger (2012)	111 (48 M, 63 F); A = 19.6; E = 3.8; CSO	U.S.	Q	14 DAS	T	Z	AD	0.38
36	Nesbit and Conger (2012)	130; A = 18.85; E = 3.64; CSO	U.S.	Q	O	T	Z	AD	0.28
37	Bachoo et al. (2013)	306 (165 M, 141 F); A = 27.2; E = 6.67; CSO	South Africa	Q	14 DAS	T	Z	RD	0.11
38	Berdoulat et al. (2013)	455 (318 M, 137 F);	France	Q	33 DAS	T	Z	AD	0.32
		A = 32.12; E = UR;				T	Z	RD	0.23
						T	Z	DE	0.18
39	Beck et al. (2013)	769 (219 M, 550 F);	U.S.	Q	14 DAS	T	Z	RD	0.28
		A = 20.5; E = UR; CSO				T	M	RD	0.29
40	Blankenship et al. (2013)	201 (93 M, 108 F); A = 19.26; E = 3.28; CSO	U.S.	Q	14 DAS	T	Z	AD	0.25
41	Herrero-Fernández (2013)	198 (69 M, 129 F); A = 27.74; E = UR	Spain	Q	14 DAS	T	Z	AD	0.31
42	Roidl et al. (2013b)	154 (49 M, 105 F); A = 22.66; E = 4.87	Germany	S	14 DAS & O	S	M	RD	0.13
43	Sarma et al. (2013)	1638 (902 M, 735 F); A = 35.95; E = UR	Ireland	Q	14 DAS	T	Z	RD	0.22
44	Sullman and Stephens (2013)	213 (92 M, 121 F);	New Zealand	Q	14 DAS	T	Z	RD	0.22
		A = 43.96;E = 25.73				T	Z	NM	0.25
						T	Z	AC	0.04
						T	M	RD	0.13
						T	M	NM	0.25
45	Sullman et al. (2013)	282 (282 M, 0 F);	Turkey	Q	14 DAS	T	Z	AD	0.15
		A = 43.4; E = 21				T	Z	RD	0.26
46	Li et al. (2014)	411 (262 M, 149 F) A = 37.9; E = = 7.11	China	Q	33 DAS	T	Z	AD	0.19
47	Kovácsová et al. (2014)	612 (382 M, 230 F);	Slovakia	Q	14 DAS	T	Z	AD	0.25
		A = 33.19; E = 13.38)				T	M	AD	0.24
48	Stephens and Ohtsuka (2014)	220 (106 M; 114 F); A = 30; E = 11	Australia	Q	14 DAS	T	Z	AD	0.49
49	Sullman et al. (2014)	339 (147 M, 192 F); A = 26; E = 8	Malaysia	Q	33 DAS	T	Z	AD	0.25
50	Vallières et al. (2014)	Study 1: 102 (67 M, 32	Canada	Q	O	S	Z	AD	0.69
		F; 3 UR); A = 22.91;				S	M	AD	0.49
		Study 2: 458 (193 M,				S	Z	AD	0.49
		262 F); A = 47.79;				S	M	AD	0.45
51	Sullman (2015)	672 (382 M, 315 F);	New Zealand	Q	14 DAS	T	Z	AD	0.37
		A = 49; E = 30				T	Z	RD	0.20
						T	Z	NM	0.12
						T	Z	AC	−0.01
						T	M	AD	0.33

Note: A: age; E: driving experience; UR: unreported; CSO: college students only; Q: questionnaire-based method; O: other methods; DAS: driving anger scale; S: situational driving anger; T: trait driving anger; Z: zero-order correlation; M: multiple correlation; AD: aggressive driving; RD: risky driving; DE: driving errors; NM: near misses; AC: accidents.

*Studies also included in the previous meta-analysis work of Nesbit et al. (2007).

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