

Long-Term Prediction of Traffic Accident Record From Bus Driver Celeration Behavior

Anders E. af Wåhlberg

Department of Psychology, Uppsala University, Uppsala, Sweden

Driver celeration (speed change) behavior of bus drivers measured a number of times was used to predict their culpable accidents over increasing time periods. It was found that predictive power was considerable (>.30 correlation) over 5 years of time with aggregated celeration (mean of repeated measurements) as independent variables, and there were also indications that power reached even further, although too low Ns made these results unreliable. Similarly, there were indications of even stronger correlations with increased aggregation of celeration values. The results were discussed in terms of the methodology needed to bring out such results, and the stability of accident-causing behavior over time.

bus driver celeration traffic accident culpability

1. INTRODUCTION

The prediction of accident record from other variables has been a main research area within traffic as well as industrial psychology for a long time, actually ever since some British scientists discovered the nonrandom distribution of injuries in various populations in the early 20th century (e.g., [1]). From this, the notion comes that if some people have more accidents than others in a similar environment and exposure, this ought to be due to something about these persons which makes them cause mishaps, or make them unable to avoid them. If these individual differences can be discovered, they can be used for identification of high-risk individuals, which can be targeted for training or limiting of their exposure, thus increasing the general level of safety in the environment where these individuals are operating. As the economic costs due to accidents are enormous, not to mention the many lives that could be saved,

such options are very attractive to companies and society. Unfortunately, no one has so far found a really strong predictor of accidents of any kind.

The reasons for the commonly weak results of traffic accident prediction studies (and possibly other accidents too) can be suspected to be manifold. For the present, it can be noted that traffic accident record is notoriously unreliable over such short time periods as is usually used by traffic researchers in their prediction studies (3 years is the most common [2]). However, reliability increases strongly with the mean of accidents in the population (af Wåhlberg, unpublished meta-analysis), and it would therefore seem like it would be advantageous to use a somewhat longer period for the calculation of the criterion in such studies. Unfortunately, as self-reported accidents are the norm within this research area, this is usually not really feasible, as memory effects will rapidly lower the quality of the data when the period is extended [3, 4, 5].

The driver celeration behavior data used in this study was gathered as part of a project on fuel efficient driving funded by the Swedish Road Administration, grant AL90AB 2001:7758. Hanna Skagerström did all the basic data editing and transformations, and in general kept things in order. As usual, the personnel at Gamla Uppsalabuss helped out in various ways. Thanks to Mats Hammarström at Uppsalabuss for providing additional data. Professor Lennart Melin (Department of Psychology, Uppsala University) supplied useful input for the project and the development of the driver celeration behavior theory.

Correspondence and requests for offprints should be sent to Anders E. af Wåhlberg, Department of Psychology, Uppsala University, P.O. Box 1225, 751 42 Uppsala, Sweden. E-mail: <anders.af_wahlberg@psyk.uu.se>.

However, there is also the problem of the validity of the predictor. Most often, accident researchers would seem to disregard the possibility of changes in their predictors over time; studies using repeated measurements over extended periods are almost unheard of. As most of these researchers would seem to have little interest in the reliability of their variables [2], this is understandable.

A theory about the relation between driving behavior and traffic accidents has been proposed, which incorporates some of these problems [6]. Basically, it assumes that all speed changes (celerations) the drivers cause their vehicles to undertake have some miniscule risks to them. Therefore, if drivers' speed changes are measured and summed, this sum will be approximately equal to their accident records (both variables standardized) within a population with similar exposure (in terms of quality, quantity is handled directly by the theory). The predictive power is expected to increase with the time period used.

However, when doing empirical research on this theory, it has so far not been possible to actually measure a group of drivers continuously for several years (which would be preferable, given the rather low reliability of celeration behavior [7]). Therefore, several measurement problems appear, like the validity over time of a single measurement. In the present paper, such problems will be investigated.

Using a set of celeration data based on several thousands of hours of driving of bus drivers, it has previously been shown that this variable is indeed predictive of accidents [8], although the reliability (correlations between single measurements) is not high. However, it has also been shown that both reliability and predictive power (for 2 years of accidents) increases when data is aggregated over measurements [9]. What has not been shown is whether the predictive power of celeration extends beyond 2 years, the only time frame which yielded significant correlations in af Wåhlberg [8], and which was then used in other investigations, where time period was not of interest, because other predictions were tested [10, 11].

In the previous studies, single celeration measurements yielded correlations of about .20

with culpable accidents during a 2-year period. Generally, shorter and longer periods did not result in significant associations. While a one-year period could be expected not to do so, given the very small variance in the criterion (these drivers have about 0.3 accidents per year), the lack of success for longer periods needed a different explanation. Given the discussion above about reliability, it could, however, easily be suspected that drivers change their behavior somewhat over time, and a measurement taken at time A may have very little validity at time B, and vice versa. Therefore, single measurements would only be expected to predict the accidents very close to them in time. But if the mean of measurements at times A and B is used as a predictor, it should predict crashes for the time between them and somewhat beyond as well, depending upon the reliability of the variable. Therefore, testing of long-range predictive power should be undertaken in steps of aggregation of both predictor and criterion, so as to determine for how long a period a certain aggregation of the independent variable has any association with the dependent parameter.

Summing up, the present paper set out to study for how long time periods celeration behavior measurements made at specific points in time could predict accident record, when aggregated at different levels.

2. METHOD

2.1. Samples

The population from which samples were drawn was all the drivers at Gamla Uppsalabuss (GUB) in Uppsala, Sweden, a town of some 200000 inhabitants. GUB runs all the city bus routes, and has about 180 buses and 350 drivers at any one time. The turnover rate of drivers is fairly high. Table 1 presents descriptive data for some samples and the population.

As the study used repeated measurements, all drivers measured could be regarded as a sample, some of them with a single measurement, others with more than a dozen. However, as

TABLE 1. Descriptive Data on the Drivers in the Samples at the Second Level of Aggregation, and of the Population at the Times When These Samples Were Gathered. Ethnicity (Percentage of Drivers With Swedish Names), Gender (Percentage of Men), the Means of Hours Worked per Year, the Number of Culpable Accidents per Year, Age (at the End of Each Year) and the Number of Years Working for Gamla Uppsalabuss (GUB)

Drivers	N	Ethnicity (%)	Gender (%)	Hours Worked	Culpable Accidents	Age	Experience
Samples 1–9	112	42.3	86.6	1 443.4	0.34 (2001)	45.1 (2001)	9.3 years (2001)
Population in 2001	413	56.9	89.3	1 217.6	0.22	44.9	10.1 years
Samples 11–18	128	46.9	89.1	1 689.9	0.26 (2002)	45.7	9.8 years (2002)
Population in 2002	397	53.7	88.9	1 306.2	0.18	46.1	11.2 years
Samples 19–28	22	22.7	90.9	1 733.5	0.36 (2003)	44.4	6.1 years (2003)
Population in 2003	419	52.7	89.0	1 260.4	0.21	45.7	10.7

TABLE 2. The Grouping of Data in Samples. The First Sample of Each Period (Season) Contains the First Measurement of All Drivers Who Yielded Any Data During That Time, the Second and Third Are Repeated Measurements on Those in the First, Which Leads to a Shrinking N Within Any Sampling Period. Not All of These Samples Used in the Present Paper, Due to Very Small Ns. Summer Data Excluded Due to Very Little Traffic

Samples	Time Period	Season
1–3	August–December 2001	Fall
4–6	December 2001–February 2002	Winter
7–9	March–June 2002	Spring
10–15	August–December 2002	Fall
16–18	January–March 2003	Winter
19–21	April–June 2003	Spring
22–26	August–December 2003	Fall
27–28	January–March 2004	Winter

the measurements took place over several years (2001–2004), a temporal ordering was deemed necessary, and several samples were therefore constructed (see Table 2 and Appendix). These were numbered consecutively, and ordered within seasons, with the exact cut-off decided by the weather. For the present study, however, season was the lowest unit of aggregation used, as single measurements (one sample) had been shown not to have any predictive power versus accidents beyond 2 years. Therefore, the mean of all available measurements per driver per season was calculated, which means from one to as many as there were samples within each season (usually there). Thereafter, a further aggregation was undertaken, taking the mean from two or three

seasons and calculating a new mean. It should be pointed out that there is a slight difference between this method and that used for calculating the mean within a season. As noted, in the latter, the mean was computed for each driver who had been measured, regardless of the number of measurements. Over seasons, however, only drivers with measurements in all of them were used, because otherwise there would be a few drivers with no values from a fairly long time period, which was not the aim of this calculation.

2.2. Celeration Behavior Data

Data was gathered by installing vehicle computers under the dashboard of five Volvo buses running on the same route. This arrangement was undertaken in co-operation with GUB to evaluate training in fuel-efficient driving [12, 13]. Speed was automatically measured and longitudinal speed changes calculated (see Appendix for details). Each measurement was the absolute mean of all speed changes undertaken by the driver while driving along the route from terminus to terminus at least once. Each such value was therefore based on at least 12 km of driving, which probably gave it a fairly good split-half reliability (this bus route yielded split-half correlations of .39 and .62 in a previous study [14]).

2.3. Accident Data

All mishaps during driving which resulted in damage (apart from intentional sabotage) or injury had been collected from the bus company's

archive and entered into a database [15, 16]. From this set, accidents for which the driver was deemed to be at least partly responsible were drawn for the drivers whose celeration behavior had been measured. Accidents were arranged per year for each driver.

Regarding culpability for accidents, very different percentages of wholly and partly responsible drivers have been reported in different studies [17, 18, 19¹, 20, 21]. It can therefore be suspected that the criterion used when determining culpability in each case differs, and that many in fact have got it wrong. For the present data, however, the criterion is probably fairly correct, as the data show features which could be expected, like a close to zero correlation between culpable and nonculpable accidents [22].

3. RESULTS

Presenting results of an analysis that uses a criterion consisting of culpable accidents for different time periods is somewhat cumbersome,

as this method leads to different numbers of drivers being available for inclusion for different periods. Two choices are possible; either use all drivers for each period, or use only those who are present for the longest period. In the present paper, it was decided to use both methods, as each can be criticized for leaving out important results. Furthermore, results can differ due to the start and end points in time. Therefore, different points were tested, each creating a series of correlations between measurements and accidents for time periods of differing length. Only those that yielded interpretable series of correlations, i.e., mainly significant ones, have been presented in the tables.

First, the celeration data for each season each year was used as predictors (the mean of all available measurements for each driver). The results can be seen in Tables 3–4. It is noteworthy that the feature expected at this level of aggregation, a tendency for prediction to be at its best close in time to the measurements, was not present. Instead, it was the shortest time periods

TABLE 3. The Correlations Between Bus Drivers’ Celeration Behavior, Aggregated Over One Season, and Their Culpable Accidents for 2001–2005 in Different Combinations. Two Largely Overlapping Samples Were Used; the Attrition Sample, Starting With All Drivers Measured at Each Time and Working at Least 2 Years, and Thereafter Dwindling for the Longer Periods, and the Same Sample, Using Only Those Drivers Who Worked for the Whole Period. Also, the Mean Number of Measurements Per Driver, the Mean of Which Was Used for Prediction

Samples	Period	2001–2002	2001–2003	2001–2004	2001–2005	Mean No. of Measurements
1–3, Fall 2001	Attrition sample	.192** (N = 204)	.201** (N = 178)	.145 (N = 168)	.167* (N = 152)	
	Same sample (N = 152)	.210**	.190*	.141	.167*	2.08
4–6, Winter 2001–2002	Attrition sample	.245*** (N = 169)	.290*** (N = 152)	.289*** (N = 140)	.280*** (N = 126)	
	Same sample (N = 126)	.238**	.277**	.305***	.280***	1.84
7–9, Spring 2002	Attrition sample	.209** (N = 164)	.223** (N = 146)	.142 (N = 137)	.165 (N = 124)	
	Same sample (N = 124)	.206*	.203*	.156	.165	2.14
11–15, Fall 2002	Attrition sample	.256*** (N = 200)	.256*** (N = 189)	.200** (N = 183)	.173* (N = 171)	
	Same sample (N = 171)	.221**	.229**	.162*	.173*	3.18
16–18, Winter 2003	Attrition sample	.248** (N = 140)	.210* (N = 140)	.212* (N = 133)	.194* (N = 125)	
	Same sample (N = 125)	.226*	.199*	.167	.194*	1.96

¹ This study used the term “primary vehicle”, which has been interpreted as akin to culpability.

TABLE 3. (continued)

Samples	Period	2001–2002	2001–2003	2001–2004	2001–2005	Mean No. of Measurements
19–21, Spring 2003	Attrition sample	.093 (N = 121)	.113 (N = 121)	.082 (N = 117)	.069 (N = 106)	
	Same sample (N = 106)	.072	.084	.066	.069	1.92
22–26, Fall 2003	Attrition sample	.204** (N = 175)	.173* (N = 175)	.159* (N = 172)	.158* (N = 155)	
	Same sample (N = 155)	.170*	.161*	.146	.158*	3.72
27–28, Winter 2004	Attrition sample	.243 (N = 40)	.222 (N = 40)	.112 (N = 40)	.141 (N = 36)	
	Same sample (N = 36)	.254	.226	.125	.141	1.22

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$.

TABLE 4. The Correlations Between Bus Drivers' Celeration Behavior, Aggregated Over One Season, and Their Culpable Accidents for 2002–2005 in Different Combinations. Two Largely Overlapping Samples Were Used; the Attrition Sample, Starting With All Drivers Measured at Each Time and Working at Least 2 Years, and Thereafter Dwindling for the Longer Periods, and the Same Sample, Using Only Those Drivers Who Worked for the Whole Period. Also, the Mean Number of Measurements Per Driver, the Mean of Which Was Used for Prediction

Samples	Period	2002–2003	2002–2004	2002–2005	Mean No. of Measurements
1–3, Fall 2001	Attrition sample	.136 (N = 179)	.063 (N = 169)	.113 (N = 152)	
	Same sample (N = 152)	.122	.068	.113	2.08
4–6, Winter 2001–2002	Attrition sample	.245** (N = 152)	.256** (N = 140)	.249** (N = 126)	
	Same sample (N = 126)	.243**	.278**	.249**	1.84
7–9, Spring 2002	Attrition sample	.146 (N = 147)	.064 (N = 138)	.098 (N = 124)	
	Same sample (N = 124)	.118	.072	.098	2.14
11–15, Fall 2002	Attrition sample	.267*** (N = 202)	.177* (N = 193)	.151* (N = 179)	
	Same sample (N = 179)	.229**	.142	.151*	3.18
16–18, Winter 2003	Attrition sample	.208** (N = 152)	.189* (N = 142)	.173* (N = 134)	
	Same sample (N = 134)	.174*	.143	.173*	1.96
19–21, Spring 2003	Attrition sample	.205* (N = 130)	.132 (N = 124)	.107 (N = 112)	
	Same sample (N = 112)	.158	.107	.107	1.92
22–26, Fall 2003	Attrition sample	.205** (N = 187)	.176* (N = 183)	.173* (N = 166)	
	Same sample (N = 166)	.200**	.167*	.173*	3.72
27–28, Winter 2004	Attrition sample	.208 (N = 46)	.046 (N = 46)	.056 (N = 42)	
	Same sample (N = 42)	.196	.044	.056	1.22

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$.

at the beginning of each round of calculations (2001–2002 and 2001–2003) that yielded the highest correlations.

Next, celeration was aggregated into three roughly equal time periods, by adding seasons together, and the same calculations as for the first level were undertaken. Results are displayed in Tables 5–6. Although these data are harder to evaluate, as there are fewer correlations, no trends are apparent concerning closeness in time.

It should be noted that extending the time period back into the years previous to 2001 at this level of aggregation yielded results of any size and significance only for samples 1–9 (Table 7), but not for the other predictor groups. The correlations between these three predictors were .693 ($N = 45$, $p < .001$) for samples 1–9 versus 11–18 and .792 ($N = 25$, $p < .001$) for 11–18 versus 19–28. The last correlation (1–9/19–28) was higher, but N very small.

TABLE 5. The Correlations Between Bus Drivers' Celeration Behavior, Aggregated Over Two or Three Seasons, and Their Culpable Accidents for 2001–2005 in Different Combinations. Two Largely Overlapping Samples Were Used; the Attrition Sample, Starting With All Drivers Measured at Each Time and Working at Least 2 Years, and Thereafter Dwindling for the Longer Periods, and the Same Sample, Using Only Those Drivers Who Worked for the Whole Period. Also, the Mean Number of Measurements Per Driver, the Mean of Which Was Used for Prediction

Samples	Period	2001–2002	2001–2003	2001–2004	2001–2005	Mean No. of Measurements
1–9, 2001–2002	Attrition sample	.282** ($N = 112$)	.324*** ($N = 101$)	.297** ($N = 93$)	.300** ($N = 86$)	6.52
	Same sample ($N = 86$)	.298**	.314**	.322**	.300**	
11–18, 2002–2003	Attrition sample	.306*** ($N = 129$)	.283*** ($N = 129$)	.267** ($N = 125$)	.244** ($N = 119$)	5.50
	Same sample ($N = 119$)	.271**	.247**	.212*	.244**	
19–28, 2003–2004	Attrition sample	.295 ($N = 22$)	.334 ($N = 22$)	.256 ($N = 22$)	.341 ($N = 20$)	8.1
	Same sample ($N = 20$)	.352	.360	.337	.341	

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$.

TABLE 6. The Correlations Between Bus Drivers' Celeration Behavior, Aggregated Over Two or Three Seasons, and Their Culpable Accidents for 2002–2005 in Different Combinations. Two Largely Overlapping Samples Were Used; the Attrition Sample, Starting With All Drivers Measured at Each Time and Working at Least 2 Years, and Thereafter Dwindling for the Longer Periods, and the Same Sample, Using Only Those Drivers Who Worked for the Whole Period. Also, the Mean Number of Measurements Per Driver, the Mean of Which Was Used for Prediction

Samples	Period	2002–2003	2002–2004	2002–2005	Mean No. of Measurements
1–9, 2001–2002	Attrition sample	.253* ($N = 101$)	.242* ($N = 93$)	.248* ($N = 86$)	6.52
	Same sample ($N = 86$)	.256*	.271*	.248*	
11–18, 2002–2003	Attrition sample	.272*** ($N = 138$)	.229** ($N = 132$)	.196* ($N = 126$)	5.49
	Same sample ($N = 126$)	.208*	.168	.196*	
19–28, 2003–2004	Attrition sample	.304 ($N = 27$)	.196 ($N = 27$)	.208 ($N = 25$)	8.08
	Same sample ($N = 25$)	.303	.224	.208	

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$.

TABLE 7. The Correlations Between Bus Drivers' Celeration Behavior, Aggregated Over Three Seasons, and Their Culpable Accidents for 1997–2002 in Different Combinations. Two Largely Overlapping Samples Were Used; the Attrition Sample, Starting With All Drivers Measured at Each Time and Working at least 2 Years, and Thereafter Dwindling for the Longer Periods, and the Same Sample, Using Only Those Drivers Who Worked for the Whole Period. Also, the Mean Number of Measurements Per Driver, the Mean of Which Was Used for Prediction

Samples	Period	2000–2002	1999–2002	1998–2002	1997–2002	Mean No. of Measurements
1–9, 2001–2002	Attrition sample	.165 (<i>N</i> = 84)	.174 (<i>N</i> = 73)	.306* (<i>N</i> = 53)	.295* (<i>N</i> = 51)	
	Same sample (<i>N</i> = 51)	.325*	.332*	.296*	.295*	6.67

Notes. **p* < .05.

As the overlap in drivers between predictors at this level of aggregation was very small, only one further addition could be undertaken, between samples 1–9 and 11–18. The resulting variable was correlated with somewhat longer time periods than the previous lower-level variables. The results can be seen in Table 8. All correlations were very high, but *N* mainly very small. However, there would seem to be no difficulties in predicting accidents over an 8-year period.

Finally, for instructive purposes, the correlations between celeration aggregated over several seasons and single years' accidents were computed (Table 9). The unevenness of results, within and between predictors, is striking, and it can therefore be concluded that, given a mean of accidents of 0.3, it is not really feasible to use single years' crashes as criterion for this amount of data. At the highest level of celeration aggregation, however, it would seem possible to predict even such short periods with fair accuracy.

TABLE 8. The Correlations Between Bus Drivers' Celeration Behavior, Aggregated Over Five Seasons, and Their Culpable Accidents for 1998–2005. One Attrition Sample Was Used, Starting With All Drivers Measured at Each Time and Working at Least 4 Years, and Thereafter Dwindling for the Longer Periods

Samples		1998–2002	1998–2003	1998–2004	1998–2005
1–9, 11–18, 2001–2003	Attrition sample	.515* (<i>N</i> = 16)	.415 (<i>N</i> = 16)	.400 (<i>N</i> = 15)	.469 (<i>N</i> = 14)
Samples		2003–2005	2002–2005	2001–2005	2000–2005
1–9, 11–18, 2001–2003	Attrition sample	.335* (<i>N</i> = 43)	.415** (<i>N</i> = 43)	.478** (<i>N</i> = 43)	.395* (<i>N</i> = 30)

Notes. **p* < .05, ***p* < .01.

TABLE 9. The Correlations Between Bus Drivers' Celeration Behavior, Aggregated Over Two, Three or Five Seasons, and Their Culpable Accidents for Single Years. Thereafter, the Mean of These Correlations, and the Mean Number of Measurements for the Samples. Samples 19–28 Not Used, Due to Too Small *N*. Attrition Samples Not Shown, Because Values Were Very Similar to Same Samples

Samples	<i>N</i>	2001	2002	2003	2004	2005	Mean Correlation	Mean No. of Measurements
1–9, 2001–2002	86	.297**	.175	.230*	.163	.066	.201	6.52
11–18, 2002–2003	119	.136	.288***	.091	–.010	.199*	.173	5.50
1–18, 2001–2003	43	.437**	.408**	.228	.235	.210	.319	11.85

Notes. **p* < .05, ***p* < .01, ****p* < .001.

4. DISCUSSION

The present results would seem to imply that celeration behavior indeed has predictive power concerning accidents over several years from the measurement, before and after. These correlations were typically between .15 and .25 for an aggregation of about two measurements. At the next level, this range was instead between .25 and .30, with a few exceptions. Thereafter, data indicate further increases, but were too sparse to allow definitive conclusions.

The trend within the data would seem to be that predictive power depends upon the number of measurements used as predictor, but not the time period for accidents, as long as this is at least one year. In af Wåhlberg [8], correlations were reliably significant only for 2-year periods, apparently due to single measurements being used as predictors. In the present study, with more measurements, the time period with significant associations became longer, apparently stretching out for at least 3 years from the period of measurement (6 years in total), but probably longer. Somewhat anomalous, if this principle is accepted, were the results for the years prior to 2001 at the second level of aggregation. Although it was reasonable that only the first set of measurements had any association with this period, being closest in time to it, the correlations were very strong for a very long period (actually even longer than what was reported), while for the other sets, predictive power dropped abruptly with this extension. However, with the final aggregation, this drop disappeared.

On the other hand, no trend towards stronger correlations for longer time periods was discernible, not even at the highest level of aggregation, when measurements were extended over a considerable period. No apparent explanation for this result could be found. However, it is possible that the sought effect is in fact much weaker than other sources of variation, and therefore not visible in these data. Such an explanation, on the other hand, would need to specify what these other factors are.

The intercorrelations between celeration behavior, measured at different times, were

rather high at the second level of aggregation. However, as can be seen from the number of measurements, these are actually rather few, as compared to the total amount of driving these bus drivers undertake. Previously, it has been shown that the amount of explained variance in accident record for a 2-year period for these drivers increases about 0.8 percent units with each added measurement [9]. Given these results, and the very high correlations with accidents for the final aggregation, it would seem that it would be quite possible to explain more than 15% of the variation in accidents for a 5-year period, given at least 10 measurements during this time, and a mean of at least 0.5 accidents per driver per year. Such predictive power would seem to be unrivalled within traffic psychology today, although the use of mainly low-risk populations (car drivers) as subjects for accident studies makes comparisons hard.

One of the consequences of this study would seem to be that driver behavior is rather stable over time frames of almost a decade. If not, there would be no predictive power from the celeration variable for the longer periods. Such results have rarely been reported anywhere else in the traffic safety literature. Indications can be found in some of the accident record stability studies [23, 24, 25, 26] and one or two accident prediction studies showing significant associations with accidents over long time frames (e.g., [27]).

The celeration behavior theory has received a fair backing from the research undertaken so far. Although the results from the first two studies [14, 28] were uneven and inconclusive, this was probably due to small *N*s and very little celeration data for each driver. When these limitations had been overcome, things started looking very different. So far, it has been shown, not only that celeration behavior has a positive association with traffic accidents, but also that this variable is a stronger predictor than acceleration and deceleration [8] and possibly various variants of speed [10], all as predicted by theory. Also, although not tests of predictions, but of some practical significance, results have shown that celeration behavior has some stability over time [7], that predictive power increases with

aggregation [9], and that there are methodological problems involved in the measurement which, when removed, increase correlations with accidents [11].

Considering the possibilities of these results for further research and practical applications, it is instructive to recap what research was a precursor of the celeration behavior theory, how it was undertaken, and what methodological features can be considered necessary for a powerful predictive capacity (i.e., a successful study of this subject). The only empirical studies found that have used acceleration measures² to predict accident involvement are Lajunen, Karola and Summala [29], Lajunen and Summala [30] and Quimby, Maycock, Palmer, et al. [31]. Their results were weak, probably due to several methodological shortcomings. First, drivers were only measured once, thus probably yielding a measure with rather low reliability. Second, drivers were aware of being under surveillance, which probably altered their behavior [33]. Third, these subjects were car drivers with a very low mean number of accidents, and statistical power was therefore low. Fourth, these studies seem to have used the principles of Robertson, Winnett and Herrod [32] for their acceleration calculations, which probably yield slightly different values from the celeration method.

So, it is therefore recommended that at least an hour's driving be used for calculating a driver's celeration value for a single measurement. This driving should be undertaken in the motorist's normal driving environment, where the accidents used as criterion should also have happened. Furthermore, measurements should preferably be unknown to the drivers, although with the long series advocated, this is probably not necessary. For all populations, the accident record should span several years, preferably for the same period as the measurements, which should be undertaken at least a few times each year. Finally, the mathematical principles used for calculations should be the ones presented in af Wåhlberg [6], as these are predicted to yield the best results (although differences are probably very small).

The weakness of the results from celeration behavior theory so far is that they all come from the same population, or group, of drivers. Although results are very positive, it can always be argued that there is something special about bus drivers, or even this one company, which could explain the results. Replications, as well as practical applications, are therefore needed. There are also other predictions made by the celeration behavior theory that can be tested. For example, one consequence of the basic assumption of speed change equaling risk is that no other accident predictor can be stronger, if they are measured under the same time period [6].

The celeration theory is so far strictly about behavior and its relation to accidents. It contains no mechanism for how this behavior is instigated or regulated (automatically or consciously, for example), issues that have been raised by reviewers. Here, it can only be said that such developments would be welcome, although whether they would increase the predictive power of the theory versus accidents remains to be seen.

REFERENCES

1. Greenwood M, Yule GU. An enquiry into the nature of frequency distributions representative of multiple happenings, with particular reference to the occurrence of multiple attacks of disease or of repeated accidents. *J Roy Stat Soc.* 1920;83:255–79.
2. af Wåhlberg AE. Some methodological deficiencies in studies on traffic accident predictors. *Acc Anal Prev.* 2003;35: 473–86.
3. Maycock J, Lockwood C, Lester JF. The accident liability of car drivers (TRRL research report No. 315). Crowthorne, UK: Transport and Road Research Laboratory (TRRL); 1991.
4. Maycock G, Lester J. 1995. Accident liability of car drivers: follow-up study. In: Grayson GB, editor. *Behavioural research in road safety V*. Crowthorne, UK: Transport Research Laboratory; 1995. p. 106–20.

² Variables that probably have high associations with celeration have been used by a somewhat larger number of researchers [6].

5. Chapman P, Underwood G. Forgetting near-accidents: the roles of severity, culpability and experience in the poor recall of dangerous driving situations. *App Cogn Psy*. 2000;14:31–44.
6. af Wåhlberg AE. The prediction of traffic accident involvement from driving behavior [doctoral dissertation]. Uppsala, Sweden: Uppsala University; 2006.
7. af Wåhlberg AE. Stability and correlates of driver acceleration behaviour. In: Dorn L, editor. *Driver Behaviour and Training, Proceedings of the First International Conference on Driver Behaviour and Training*. Aldershot, UK: Ashgate; 2003. p. 45–54.
8. af Wåhlberg AE. Driver celeration behavior and the prediction of traffic accidents. *International Journal of Occupational Safety and Ergonomics (JOSE)*. 2006;12:281–96.
9. af Wåhlberg AE. Aggregation of driver celeration behavior data: effects on stability and accident prediction. *Saf Sci*. 2007;45:487–500.
10. af Wåhlberg AE. Speed choice versus celeration behavior as traffic accident predictor. *J Saf Res*. 2006;37:43–51.
11. af Wåhlberg AE. Effects of passengers on bus driver celeration behavior and incident prediction. *J Saf Res*. 2007;38:9–15.
12. af Wåhlberg AE. Fuel efficient driving training—state of the art and quantification of effects. In: *Proceedings of Soric'02*. Manama, Bahrain; 2002. Available from: http://www.psyk.uu.se/hemsidor/busdriver/af_Wahlberg_Fuel_efficient_driving_training.pdf
13. af Wåhlberg AE. Long term effects of training in economical driving; fuel consumption, accidents, driver acceleration behavior and technical feedback. *I J Ind Erg*. In press.
14. af Wåhlberg AE. The stability of driver acceleration behavior, and a replication of its relation to bus accidents. *Acc Anal Prev*. 2004;36:83–92.
15. af Wåhlberg AE. Characteristics of low speed accidents with buses in public transport. *Acc Anal Prev*. 2002;34:637–47.
16. af Wåhlberg AE. Characteristics of low speed accidents with buses in public transport. Part II. *Acc Anal Prev*. 2004;36:63–71.
17. Cation WL, Mount GE, Brenner R. Variability of reaction time and susceptibility to automobile accidents. *J App Psy*. 1951;35:101–7.
18. Brandaleone H, Flamm E. Psychological testing: effect on the accident frequency of bus operators. *Ind Med Surg*. 1955;24:296–8.
19. Munden JW. The relation between a driver's speed and his accident rate (RRL report No. 88). Crowthorne, UK: Road Research Laboratory (RRL); 1967.
20. Quimby AR, Maycock G, Carter ID, Dixon R, Wall JG. Perceptual abilities of accident involved drivers (TRRL research report No. 27). Crowthorne, UK: Transport and Road Research Laboratory (TRRL); 1986.
21. Dobson A, Brown W, Ball J, Powers J, McFadden M. Women drivers' behaviour, socio-demographic characteristics and accidents. *Acc Anal Prev*. 1999;31:525–35.
22. af Wåhlberg AE, Dorn L. Bus driver accident record; the return of accident proneness. *J Safety Res*. In press.
23. Bach H, Bickel H, Biehl B. Validierung von Testverfahren zur Fahrer-Auslese am Unfallkriterium. *Zeit Verk*. 1975;21:27–38.
24. Häkkinen S. Traffic accidents and professional driver characteristics: a follow-up study. *Acc Anal Prev*. 1979;11:7–18.
25. Gebers MA, Peck RC. An inventory of California driver accident risk factors. Sacramento, CA, USA: California Department of Motor Vehicles; 1994.
26. Blasco RD, Prieto JM, Cornejo JM. Accident probability after accident occurrence. *Saf Sci*. 2003;41:481–501.
27. Williams JR. Follow-up study of relationships between perceptual style measures and telephone company vehicle accidents. *J App Psy*. 1977;62:751–4.
28. af Wåhlberg AE. The relation of acceleration force to traffic accident frequency: a pilot study. *Traf Res P F: Traf Psy Beh*. 2000;3:29–38.

29. Lajunen T, Karola J, Summala H. Speed and acceleration as measures of driving style in young male drivers. *Perc Mot Ski.* 1997;85:3–16.
30. Lajunen T, Summala H. Effects of driving experience, personality, driver's skill and safety orientation on speed regulation and accidents. In: Rothengatter T, Carbonell Vaya E, editors. *Traffic and transport psychology, theory and application.* Amsterdam, The Netherlands: Pergamon; 1997. p. 283–94.
31. Quimby A, Maycock G, Palmer C, Grayson GB. Drivers' speed choice: an in-depth study (TRL report No. 326). Crowthorne, UK: Transport Research Laboratory (TRL); 1999.
32. Robertson DI, Winnett MA, Herrod RT. Acceleration signatures. *Traf Eng Con.* 1992;33:485–91.
33. af Wåhlberg AE, Melin L. Driver acceleration behavior in training and regular driving. In: Dorn L, editor. *Driver behaviour and training, volume III. Proceedings of the Third International Conference on Driver Behaviour and Training, 2007.* Aldershot, UK: Ashgate. In press.

APPENDIX

Calculation of the Celeration Variable and Ordering of Measurements

The predictor variable came from the measurement of pulses from the speedometer system of the buses. These pulses signify that a certain length of road has been traveled (for the buses in the present study 1/6900 of a kilometer). By counting the number of pulses for a time period (given by the internal clock of the measurement system), it was possible to calculate speed during this time period.

The speed signal was tapped from the vehicle's speedometer with a frequency of 10 Hz, an interval of 100 ms. During this interval, the number of complete pulse-cycles was counted, and speed and acceleration calculated with the formulas below.

The measurements equipment was developed by Drivec AB (now VDI Innovation).

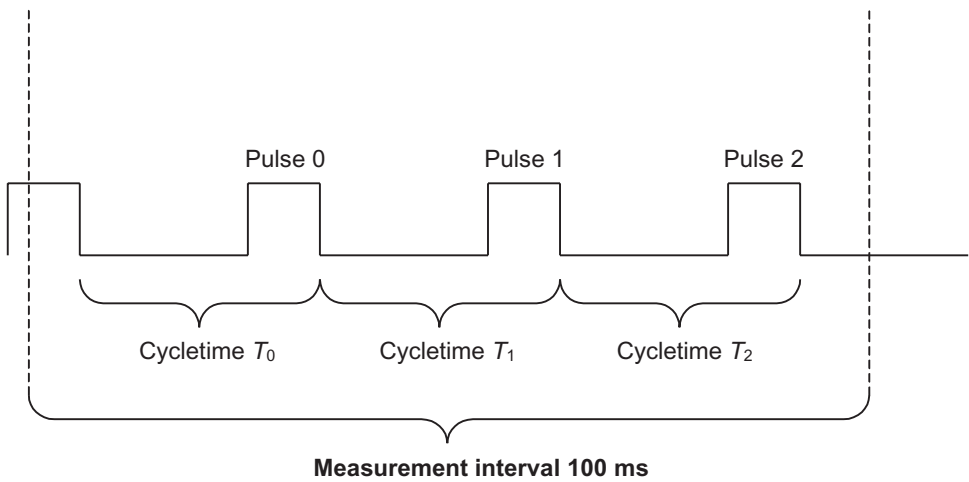


Figure 1. Example.

Example

$$t = T_0 + T_1 + T_2, n = 3.$$

Speed calculation formula:

$$v = ((n/t)/w) \bullet 1000,$$

where v —speed (m/s), n —number of pulses from the speedometer, t —time for n pulses to accumulate (seconds), w —pulses per kilometer.

Acceleration calculation formula:

$$a_{(4\ n)} = ((v_{(4\ n)} + v_{(4\ n+1)} + v_{(4\ n+2)} + v_{(4\ n+3)})/4 - (v_{(4\ n)} + v_{(4\ n-1)} + v_{(4\ n-2)} + v_{(4\ n-3)})/4)/2.5,$$

where a —acceleration (m/s^2), v —speed (m/s), n —number of acceleration measurement points.

Calculation of Predictors

The data from the measurement system was given as several columns of values (of which only speed, v , and speed change are of importance here), with each case representing a time frame (0.1 s for speed, 0.4 s for speed changes). From such a file, the mean acceleration value was computed for a time segment (cases 1 to n), which had been identified as having been driven by a certain driver.

Celeration was calculated as the absolute mean of all speed changes when $v > 0$.

Ordering of Measurements

As measuring was always operative for several years, drivers who worked a lot, and on certain duty rotation lists, tended to be measured several times, while others were rarely so. To utilize as much data as possible, but still retain a data arrangement that was ordered in time, these repeated measurements were ordered into samples within time periods. One such period can be seen in Table A1 (where numbers designate measurement order, i.e., 1 is the first measurement of this driver). It shows that the driver Nilsson was measured three times during the fall season. These three measurements were easily ordered into the three samples of this period. Driver Jonsson, on the other hand, was only measured twice, and he will therefore be absent from the third sample. Note also that despite the first measurements of Nilsson and Jonsson being a month apart, these will still both be ordered into the first sample. Finally, although Andersson was among the last to be measured, his single value will still be put with other first measurements in sample 1 (Table A2).

TABLE A1. An Example of How the Measurements Could Be Ordered and Numbered, in Relation to the Time When They Were Taken

Driver	August	September	October	November	December
Nilsson	1		2		3
Jonsson		1	2		
Pettersson			1	2	3
Andersson					1

TABLE A2. How the Measurements in the Example in Table A1 Would Have Been Ordered Into Samples

Driver	Sample 1	Sample 2	Sample 3
Nilsson	1	2	3
Jonsson	1	2	
Pettersson	1	2	3
Andersson	1		

When the season was finished (decided by the weather), a new grouping would be started, in the aforementioned case winter, with three new samples (4–6), where the first measurement of each driver this season would be ordered into sample 4, and so on.