

Intrafamilial Transmission of Driving Behavior

Evidence from In-Vehicle Data Recorders

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This study analyzes intrafamilial transmission of driving behavior by examining driving patterns of newly licensed young drivers and their family members as recorded over a period of 9 months using in-vehicle data recorders. Various maneuvers that the drivers undertook were identified in the measurements and used to compute risk indices for each driver during each month. The correlations between risk indices of drivers within the same family were studied. The results show intrafamilial transmission of driving behavior and reveal that this transmission evolves over time, as the behavior of young drivers is initially more closely related to that of their family members but gradually develops into a more differentiated personal driving style. Higher correlations are also found for specific maneuver types, such as braking and accelerating, and to a lesser extent for other maneuvers, such as speeding. The findings of the study indicate a need to carefully consider the role played by parents in the driving education of young adults and advising parents to exert control over their offspring's driving through positive modeling, and not only through well-designed commentary during driving.

Young drivers are involved in car crashes more than any other age group, especially during their first year of unsupervised driving (1, 2). The risk of crash involvement declines with increased driving experience, but the more newly licensed teenagers drive, the more their exposure to risk increases. The dilemma faced by policy makers and parents is how to allow young drivers to gain experience without overly exposing them to increased crash risk. Graduated driver licensing (GDL) programs have been proposed and implemented to delay licensure and limit exposure to high-risk conditions after licensure. These programs emphasize the responsibility of parents as role models for driving behavior and the necessity of tailored family policies for the supervision of novice young drivers.

Several studies have examined the role of parents in education, supervision, and control of their children's driving. Adolescent problematic driving was demonstrated to be related to parenting practices, especially to low levels of parental monitoring and restrictions (3–6). Aggressive driving was shown to be reduced when parents enforced strict rules on their teens' driving, especially limitations on the number of hours of unsupervised driving (7, 8). Lower rates of serious

offenses and crashes were found to be correlated to higher family connectedness, leading to more active interest of the parents in their children's behavior (9). Given that surveys revealed that parents did not seem to limit teen driving as much as expected, simple motivational strategies were promoted to persuade parents to impose restrictions on early teen driving to limit their exposure to risk (10, 11).

Few studies have focused on intrafamilial correlations of driving behavior. Parents' driving records were found to be predictive of their children's records, and positive correlations were found both between parents' violations and their children's violations (12, 13), and between parents' crashes and their children's crashes (12, 14). Positive correlations were also found in parents' and children's self-reported driving behaviors, which lead to the conclusion that children inherit their parents' driving habits through genetic disposition and model learning (15). Studies based on self-reported driving styles also showed specific intrafamilial correlations in driving styles, most significantly between father and son and between mother and daughter (16).

The aforementioned studies analyzed data collected through traditional surveys (4, 7, 8), telephone interviews (5, 6, 10, 11), official driving records (9, 12–14), and self-reported questionnaires (9, 15, 16). However, driving records often contain incomplete or inaccurate information and do not account for measures of exposure (14). Also, self-reported measures are affected by self-enhancing bias and social desirability (16). More realistic measures, such as driving simulators or driving observations, are necessary to assess driving styles and behaviors (16). Accordingly, this study analyzes data collected with in-vehicle data recorders (IVDR), which provide unbiased and objective observations of driving behavior.

The data were collected for a period of 9 months from licensure. This period includes the two phases within the Israeli GDL program, namely the accompanied driving period and the solo driving period. The Israeli GDL program, which was implemented in 2000, allows teenagers to start taking on-road driving lessons with professional instructors at the age of 16.5 years. Learners are not allowed to drive outside these lessons until they become licensed by passing both theoretical and on-road driving tests. The road test can be taken at the minimum age of 17 years and after taking at least 28 driving lessons. For the first 3 months after licensure, referred to as the accompanied driving period, new drivers are required to be accompanied by an experienced driver who is at least 24 years old and has held a valid driving license for at least 5 years. In the following period, referred to as the solo driving period, for 2 years after licensure novice drivers are allowed to take up to two passengers, unless an experienced driver is present in the vehicle. Further details on the GDL program are provided by Lotan and Toledo (17).

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The remainder of the paper is structured as follows. The next section describes the methodology of this study by providing details about experiment setup, and data collection and analysis. The subsequent section presents the results of the correlations between the driving behavior of young drivers and that of their family members. The results relate both to the overall correlation values and to their temporal variation throughout the 9-month period. Then the results of the study are discussed.

METHOD

Data Collection

An IVDR system developed by GreenRoadTechnology was installed in vehicles participating in this study. This system monitors all trips made by the vehicle and records driver's identity, trip start and end times, trip durations, and speed and acceleration profiles. Pattern recognition algorithms reduce the large amount of raw information to meaningful observations, beyond speed and acceleration distributions, and allow the system to identify a set of maneuvers (e.g., lane changes, turns with and without acceleration, sudden braking, strong accelerations, excess speeds). These maneuvers are classified by their relative direction (to the left or to the right) and by their level of severity (moderate, intermediate, or risky), on the basis of parameters of the detailed trajectory (e.g., maneuver duration, extent of sudden changes in speed and acceleration, and the speed at which they are performed). The processed information is transmitted through wireless networks to an application server that maintains a database with vehicle-specific and driver-specific trip history that includes statistics of the vehicle usage patterns, the recorded maneuvers and their severity ratings. Further details about this IVDR system can be found in work by Toledo and Lotan (18) and Toledo et al. (19).

Participating families were all volunteers recruited using advertisements in a dedicated website, in the media, and through professional driving instructors. Participating families were screened to verify that most or all of the trips made by the newly licensed driver would be in the vehicle in which the IVDR was installed, and that this vehicle was also the main vehicle used by the accompanying person. The resulting sample considered in this study consists of 75 families. Data for newly licensed drivers were collected for 44 males and 31 females. During the entire period, these young drivers were monitored for a total of almost 13,000 driving hours, in which they recorded almost 63,000 maneuver events with intermediate or risky severity ratings. Data for family members were collected for 54 fathers, 66 mothers, and 27 brothers or sisters of the young driver. More than 26,500 driving hours and 71,500 maneuver events were recorded for these drivers. All drivers in the sample drove the equipped vehicle for at least 5 hours in each month. Because participation in the study was voluntary, the sample is not representative of the Israeli population and is likely to be biased toward self-selection of families with high awareness and willingness to participate.

As discussed above, the data collection took place over a period of 9 months, which includes both the initial 3 months after licensure in which young drivers are required to drive only when accompanied by an experienced driver (accompanied driving period) and the period thereafter (solo driving period). Initially, participating families received only minimal information about the purpose and capabilities of the IVDR and no feedback at all about the observed driving behavior in order to minimize the effect of the system on their

behavior. Approximately 4 months after the IVDR installation, families were given access codes to personal web pages containing the data collected on their driving behavior and risk indices.

Data Analysis

To analyze the intrafamilial correlation of driving behavior and to account for its variation during the 9 months, data relative to each driver within each family were aggregated on a monthly basis. In addition, maneuvers were categorized into four behavioral classes: braking and accelerating, turning, lane changing, and speeding.

Risk indices were computed for each participant during each month. These risk indices have been shown to have a significant positive correlation with drivers' crash records (19). They are computed as a linear function of the number and severity of the maneuvers in each month, normalized by the driving time in that month:

$$R_{im} = \frac{\sum_j \sum_s \beta_{js} N_{ijsm}}{DT_{im}} \quad (1)$$

where

- R_{im} = risk index for individual i during month m ,
- DT_{im} = total driving time for individual i during month m ,
- N_{ijsm} = number of maneuvers of type j and severity level s for individual i during month m , and
- β_{js} = weights of the maneuvers of type j and severity level s .

Risk indices for each class of maneuvers were similarly calculated:

$$R_{im,C} = \frac{\sum_{j \in C} \sum_s \beta_{js} N_{ijsm}}{DT_{im}} \quad (2)$$

where $R_{im,C}$ is the risk index of maneuver of class C for individual i during month m , and C indicates the maneuver class of braking and accelerating, turning, lane changing, or speeding.

Within each family, indices R_{im} and $R_{im,C}$ were computed for the young driver, as well as for all other family members driving the same vehicle. The correlation between risk indices within the family was measured by Pearson's correlation. The analysis also differentiated between male and female young drivers. Table 1 presents the number of dyads and in parentheses the number of observations over the 9-month period. Brothers and sisters were grouped together, given the limited number of cases in which older siblings drove the equipped vehicle.

Pearson's correlations were calculated using all the observations for each of the six dyad types (e.g., 270 for the father-son dyad). In addition, Pearson's correlations were calculated for each month

TABLE 1 Number of Observations for Various Dyads

	Male Young Drivers	Female Young Drivers
Father	30 (270)	24 (216)
Mother	40 (360)	26 (234)
Sibling	12 (108)	15 (135)

NOTE: Number of dyads (number of observations).

separately for each of the six dyad types (e.g., 30 for each of the 9 months for the father–son dyad) to evaluate the temporal variation of the transmission of driving behavior.

RESULTS

Overall Correlations of Risk Indices

The driving behaviors of fathers and mothers, as captured by their risk indices, did not show substantial correlation ($r = 0.0632, p = .30$). This result agrees with previous findings about gender-related differences in driving styles (20, 21), but disagrees with couple similarity found in the analysis of self-reported driving behavior (22). The risk indices of siblings were related to those of their fathers ($r = 0.2069, p = .09$), but not to those of their mothers ($r = 0.0352, p = .51$). This pattern is similar to recent findings from the investigation of self-reported behavior (23).

The correlations between risk indices of the young drivers, classified by gender, and those of their fathers, mothers, and siblings are presented in Table 2. These values clearly indicate the presence of strong intrafamilial transmission of driving behavior, but with different patterns for male and female young drivers. Specifically, male young drivers exhibit strong correlations with both their fathers and their mothers, while female young drivers are substantially correlated only with their fathers. These results are consistent with previous findings about the higher connection between the driving styles of offspring and their fathers compared with their mothers (23). However, the results do not support previous findings about an accentuated driving style connection between father and son and between mother and daughter (16). With respect to their older siblings, the correlation is substantial and significant for female young drivers, but not for male young drivers.

Correlation values between risk indices for the four classes of maneuvers discussed earlier are presented in Table 3. All four classes of maneuvers exhibit similar correlation patterns that indicate intrafamilial transmission of driving behavior from both parents to male young drivers, and from fathers and siblings to female young drivers. These correlations also provide insight into which behaviors are more relevant in the intrafamilial transmission. Specifically, young drivers appear to absorb to the largest extent from their family members braking and accelerating behavior, then turning and lane-handling behavior, and to a lesser extent speeding habits. A possible interpretation of these results may be related to the fact that during the accompanied period the driving supervision is also performed through commentary driving (24). Accordingly, young drivers might receive feedback and suggestions related to their maneuvers, and in particular the most frequent feedback might relate to braking and accelerating. During the accompanied period young drivers typically do not speed, and also

TABLE 2 Intrafamilial Correlation of Risk Indices

	Male Young Drivers	Female Young Drivers
Father	0.4553 ^a	0.4833 ^a
Mother	0.5583 ^a	0.1340
Sibling	0.1811	0.5076 ^a

^a $p < .01$.

TABLE 3 Intrafamilial Correlation of Risk Indices by Class of Maneuver

	Male Young Driver	Female Young Driver
Braking and Accelerating Maneuvers		
Father	0.5552 ^a	0.4855 ^a
Mother	0.6022 ^a	0.1579
Sibling	0.2526 ^b	0.4960 ^a
Turning Maneuvers		
Father	0.3643 ^a	0.4556 ^a
Mother	0.4516 ^a	0.1550
Sibling	0.1421	0.4365 ^a
Lane-Handling Maneuvers		
Father	0.3339 ^a	0.4430 ^a
Mother	0.4587 ^a	0.1691
Sibling	0.1537	0.4375 ^a
Speeding Maneuvers		
Father	0.2706 ^b	0.2672 ^b
Mother	0.3237 ^b	0.1079
Sibling	0.1163	0.2602 ^b

^a $p < .01$.

^b $p < .05$.

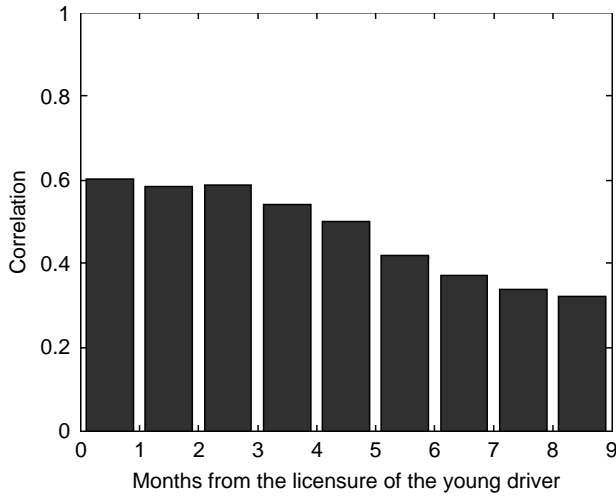
during the solo period they speed less than their family members while gaining experience, as detailed in the following section.

Correlations of Monthly Risk Indices

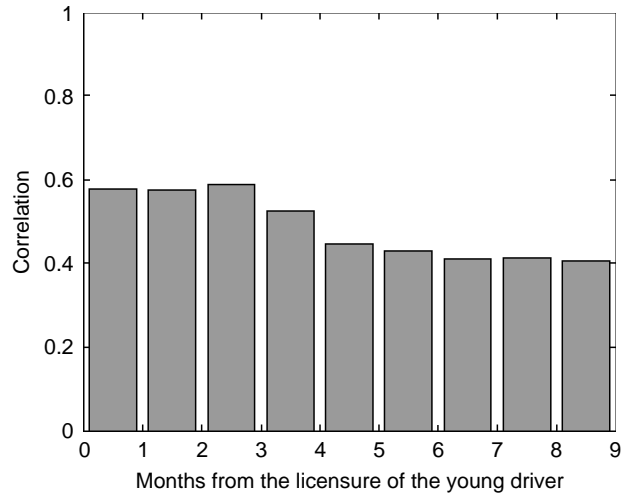
The correlations presented in the previous section suggest that the driving behavior of young drivers is inherited from their family members. During the 9-month period, young drivers acquire experience and consequently may improve their driving skills and develop their own driving style and habits. The calculation of the correlations between risk indices computed for each month provides insight into the evolution of driving behavior over time.

Figure 1 shows the variation of the correlation values between risk indices of the young drivers and of their family members over the 9-month period. The figure shows that these values exhibit a decreasing trend during the 9-month period. In all cases, the correlations are almost constant and at the highest value during the 3 months of the accompanied driving period. During the solo driving period, which starts at the 4th month after licensure, the correlations gradually decrease with time. The same general correlation pattern described above, namely the connection between male young drivers and both parents and between female young drivers and their fathers and siblings, is also observed in the monthly data.

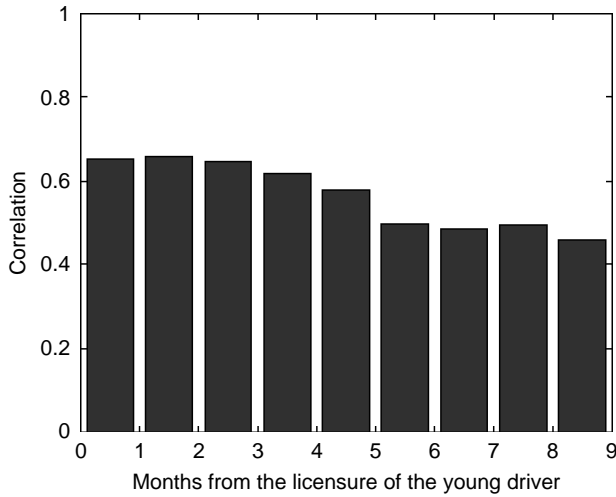
The temporal variation of the correlations might be related to changes in the behavior of the young drivers, of the family members, or both. Figure 2 presents the average monthly risk indices for all family members. The average risk indices of the parents do not change substantially throughout the duration of the study. This result may suggest that being experienced drivers, their driving styles are well established. In contrast, the risk indices for both male and female young drivers change significantly over time. This may be a result of the driving styles they develop as they gain experience. In particular,



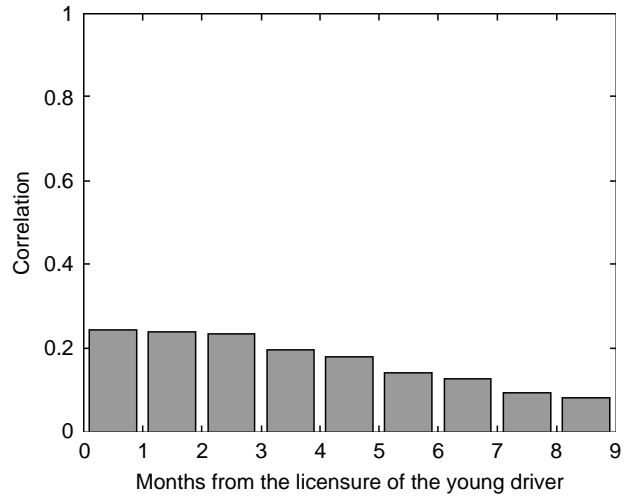
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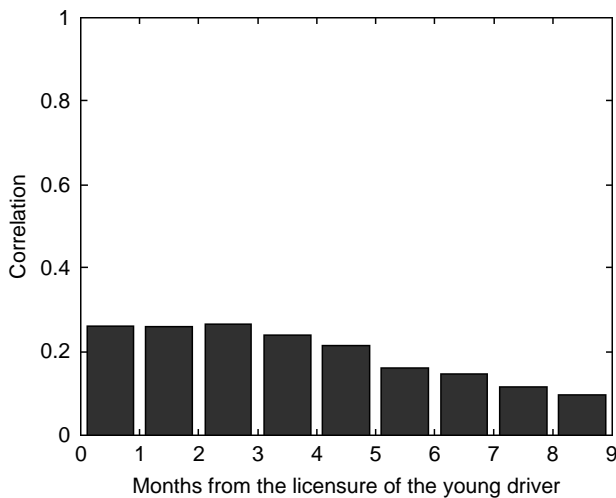
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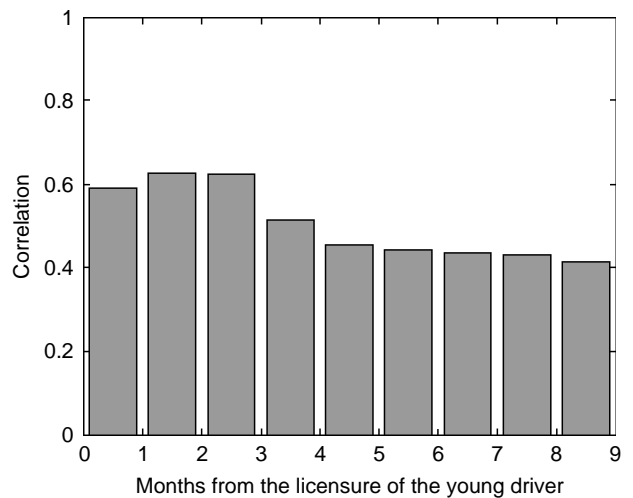
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(f)

FIGURE 1 Intrafamilial correlation of risk indices over time: (a) between male young drivers and fathers, (b) between female young drivers and fathers, (c) between male young drivers and mothers, (d) between female young drivers and mothers, (e) between male young drivers and siblings, and (f) between female young drivers and siblings.

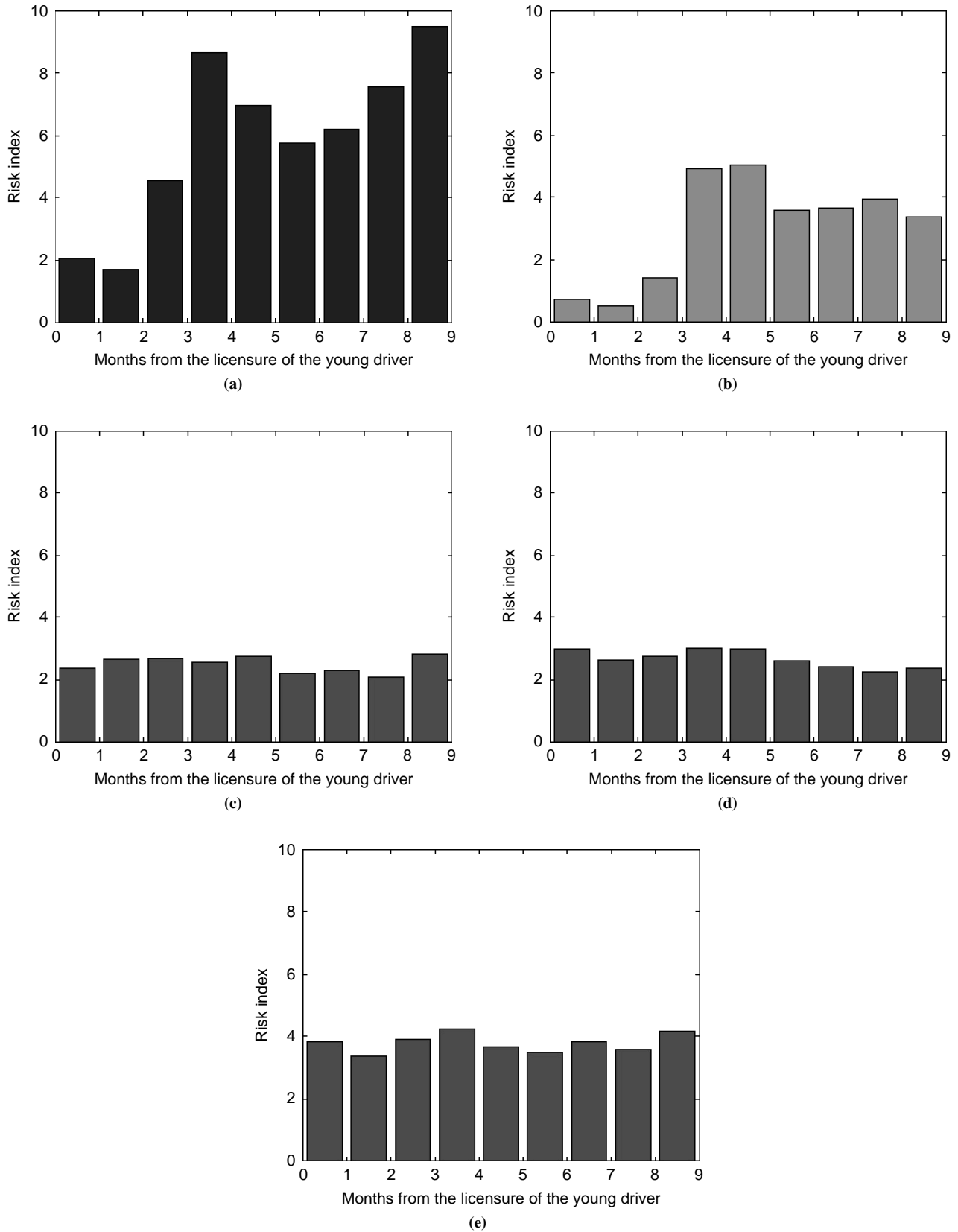


FIGURE 2 Variation of risk indices over time: (a) for male young drivers, (b) for female young drivers, (c) for fathers of young drivers, (d) for mothers of young drivers, and (e) for siblings of young drivers.

average risk indices are relatively low for both males and females during the accompanied driving period and increase significantly in the solo driving period. Average risk indices again decrease after feedback is provided to the families for the first time in the 4th month. Later, risk indices appear to stabilize for female young drivers and increase again for males. Overall, male young drivers have higher risk index values compared with females, which agrees with well-known and consolidated results in the literature (20, 21, 25). In the solo driving period, the average risk indices of both male and female young drivers is higher compared with those of their parents, which is consistent with the higher crash rates observed for these drivers.

The change of the risk indices of young drivers over time and the stability of the risk indices of other family members suggest that the temporal variation of the correlations shown in Figure 1 is a result of the changes in the behavior of the young drivers and not the other family members. A possible explanation is that in the accompanied driving period, young drivers closely follow and imitate the behavior and guidance of older family members. This may partly be with the intention of gaining parents' approval and trust in their driving ability, which could provide them greater accessibility to family vehicles. Guidelines provided to families for an effective accompanied period include motivating young drivers to gain large amounts of exposure during this period to convince their parents to feel more at ease to allow them access to the car during the solo period (24). In the solo driving period, young drivers start to develop their own driving styles and to differentiate themselves from their families, both because of the absence of the accompanying driver and the experience gained during the accompanied driving phase. At the end of the 9 months, the correlation pattern initially described is still evident: the risk indices of male young drivers are significantly correlated with those of their mothers and to a lesser extent with those of their fathers. The risk indices of female young drivers are significantly correlated with those of their fathers and their siblings, but not with those of their mothers.

Correlations of Monthly Risk Indices by Class of Maneuver

Figures 3 through 6 present the temporal variation of the correlations between risk indices of the young drivers and their family members during the 9-month period for the four maneuver classes (braking and accelerating, turning, lane-handling, and speeding maneuvers, respectively).

For braking and accelerating, turning and lane-handling maneuvers, the temporal variation of the correlation values exhibit similar patterns to the one observed for the correlations between the general risk indices. In particular, the correlation is very high during the accompanied driving period, when young drivers likely receive feedback, remarks, and suggestions from the accompanying family members. Afterward, the correlation decreases with the newly gained experience. Although the patterns are similar, the absolute correlations are somewhat higher with braking and acceleration maneuvers compared with turning and lane-handling maneuvers.

Speeding maneuvers were identified when drivers exceeded the 120 km/h threshold. The variation of the correlations of risk indices for these events, shown in Figure 6, exhibit a different pattern than the other three maneuver classes. Whereas Figure 6 shows higher correlation values in the accompanied driving period, as was the case with the other classes, the correlations are not stable, but decrease also within this period. Furthermore, the decrease in the correlation values is much steeper compared with the other maneuvers classes,

with the most substantial decrease occurring at the beginning of the solo driving period.

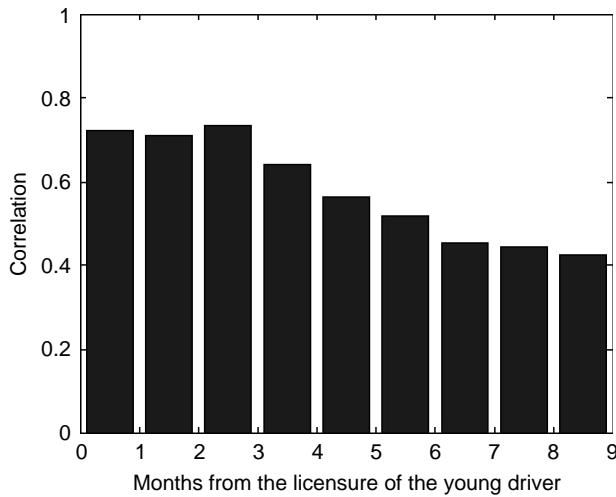
The steep decrease in the correlation values for speeding maneuvers deserves further investigation, as speeding is considered an important indicator of travel safety. Figure 7 presents the average values of the risk index for speeding maneuvers during each month, to illustrate the change in the speeding behavior of the different drivers within the family. The speeding habits of fathers and mothers are generally unchanged during the entire period. A clear gender difference emerges from the analysis of the graphs. However, the speeding behavior of both male and female young drivers is significantly altered when the accompanied driving period ends. In particular, male young drivers are involved in speeding episodes much more in the solo driving period than in the accompanied driving period and much more than are female young drivers. Male young drivers are also more affected by the feedback around the 4th month compared with female drivers. After the 6th month, the number of speeding episodes continues to increase for male young drivers, but stabilizes for female young drivers. At the end of the 9-month period, on average, fathers sped more than male young drivers and mothers sped more than female young drivers. This fact most likely contributes to the explanation of why the correlations of risk indices for the speeding maneuvers are lower compared with the other classes.

The increase of speeding events for the young drivers, and the stability of these events for their family members, indicate that the change in the correlation values over time is a result of the change in speeding behavior of young drivers and not of the other family members. A possible explanation may be that during the accompanied period the newly licensed young drivers are advised not to speed, but most likely parents with the habit of speeding are more tolerant of speeding and this explains higher correlation values. In the solo driving period, the young drivers drive without supervision and so establish their own speeding behavior. By the end of the 9 months, correlation values are low for each dyad type. The speeding behavior of young drivers may also be less correlated to the role model of the parents as other factors play a significant role, such as the type of trip performed by young drivers (in urban versus rural areas) and the social pressure of their peers (26).

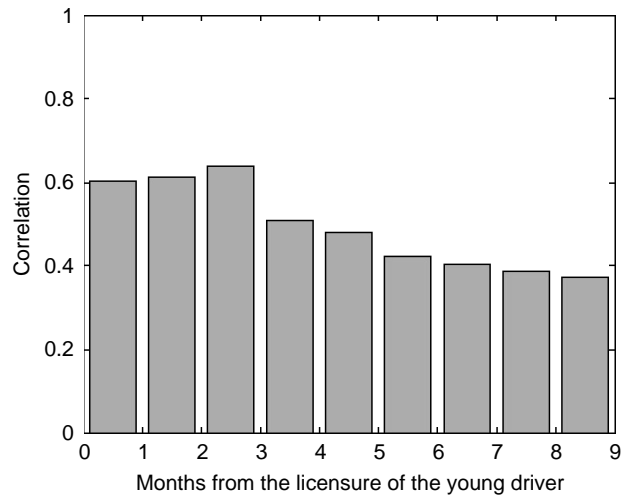
SUMMARY AND DISCUSSION

In the past, the study of the relationship between the driving behavior of parents and their children focused more on the role of parents in education, supervision, and control of their children's driving, rather than on their intrafamilial behavioral similarities. Previous studies of intrafamilial transmission of driving behavior used traditional surveys, telephone interviews, official driving records, and self-reported questionnaires, rather than directly observed driving behavior. This study focuses on the transmission of driving behavior by analyzing observations collected using IVDR systems, which have an immense potential to continuously monitor driving behavior. The recorded behavior of young drivers, fathers, mothers, and siblings within families enabled the study of the connection between the driving behavior of young drivers, by gender, and that of their parents and siblings.

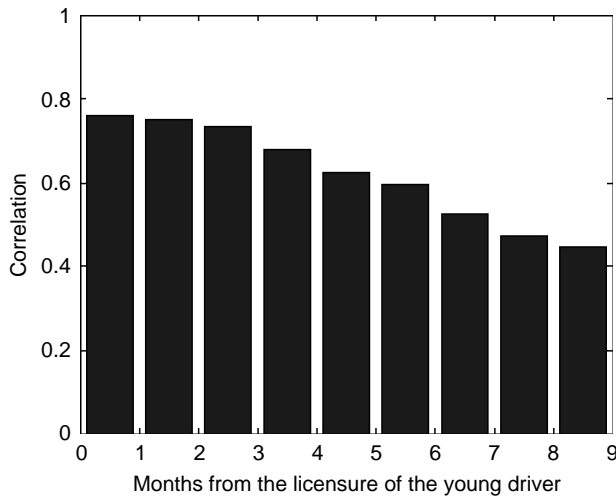
The results uncover significant correlations between the behavior of male young drivers and both their parents, and between female young drivers and their mothers and siblings. Furthermore, the correlations vary over time. During the 3 months of the accompanied driving period, the behavior of the young drivers is closely related to



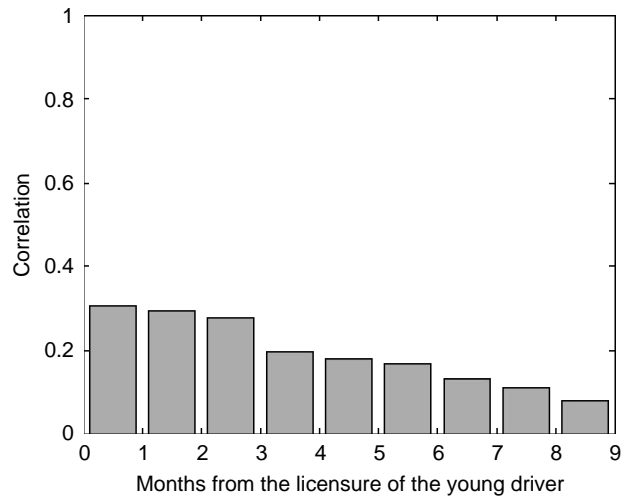
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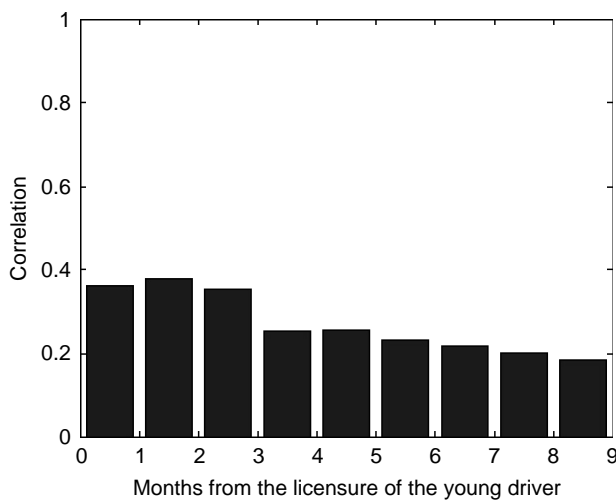
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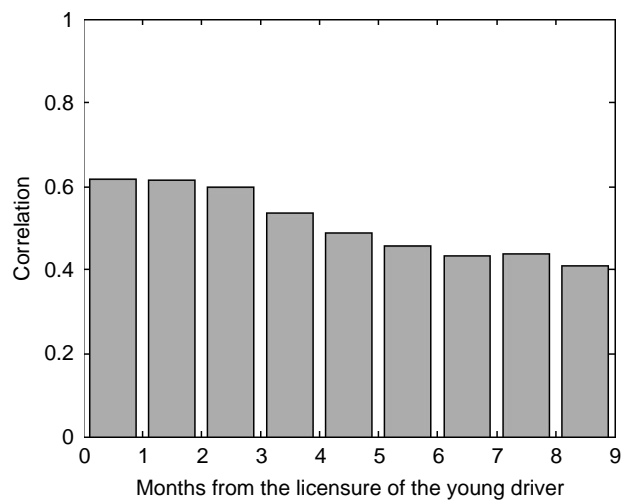
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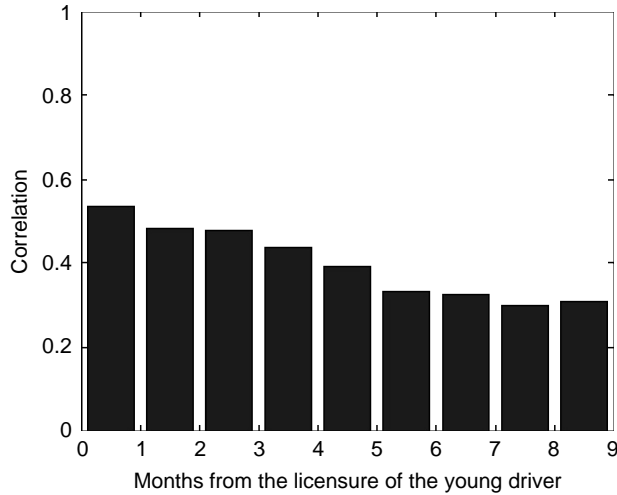


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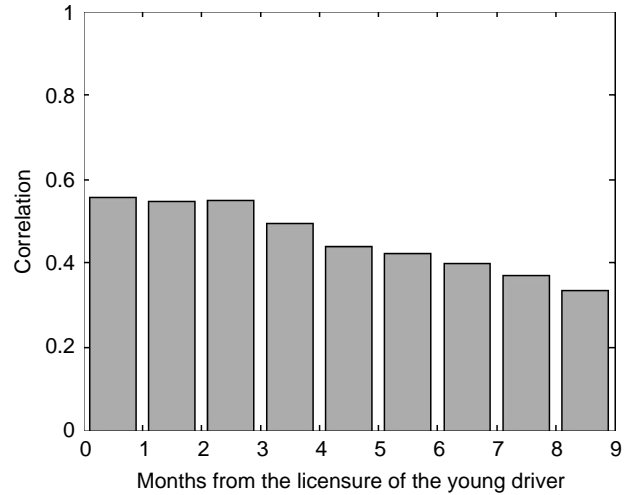


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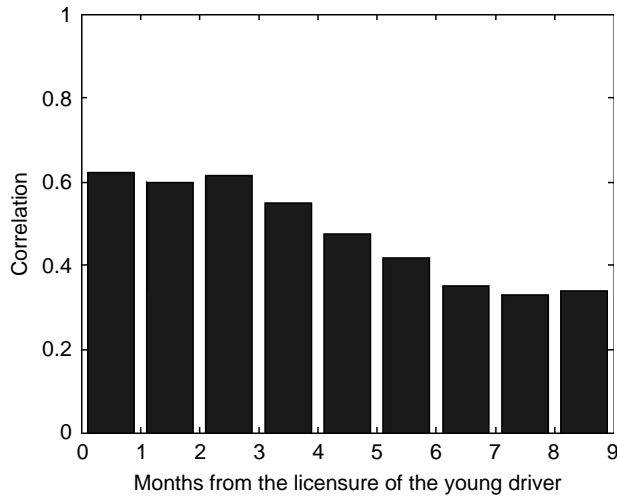
FIGURE 3 Correlation of risk indices for braking and accelerating maneuvers over time: (a) between male young drivers and fathers, (b) between female young drivers and fathers, (c) between male young drivers and mothers, (d) between female young drivers and mothers, (e) between male young drivers and siblings, and (f) between female young drivers and siblings.



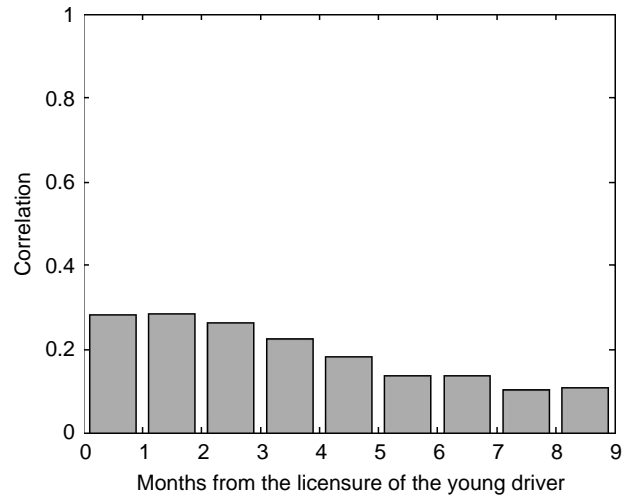
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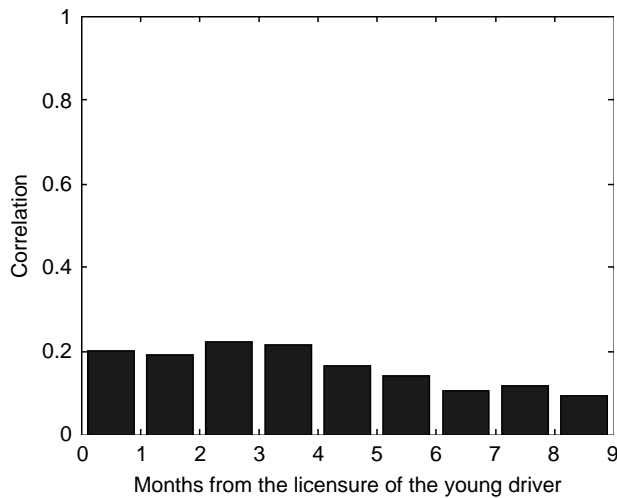
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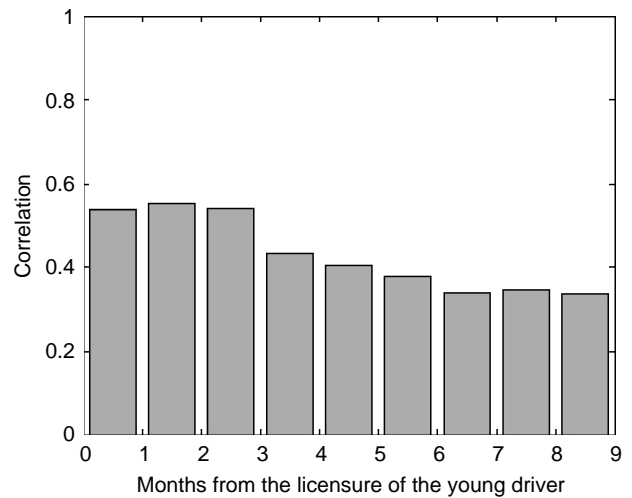
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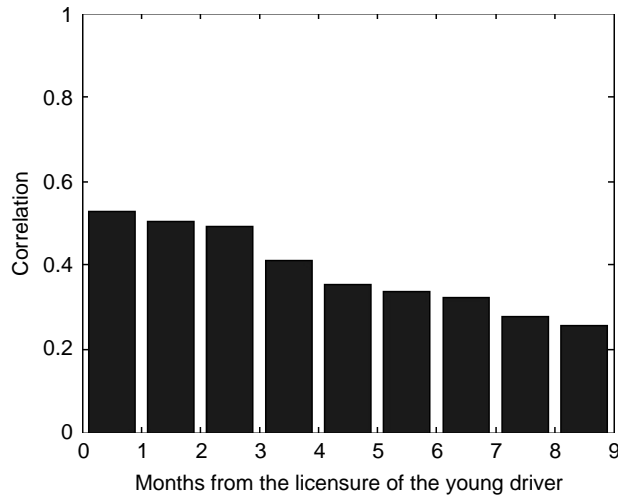


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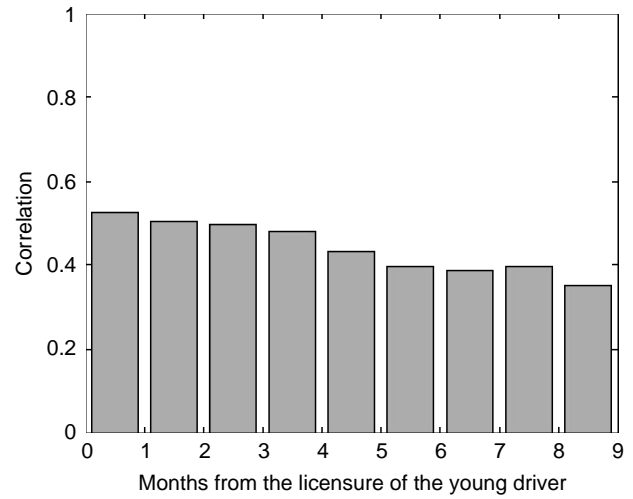


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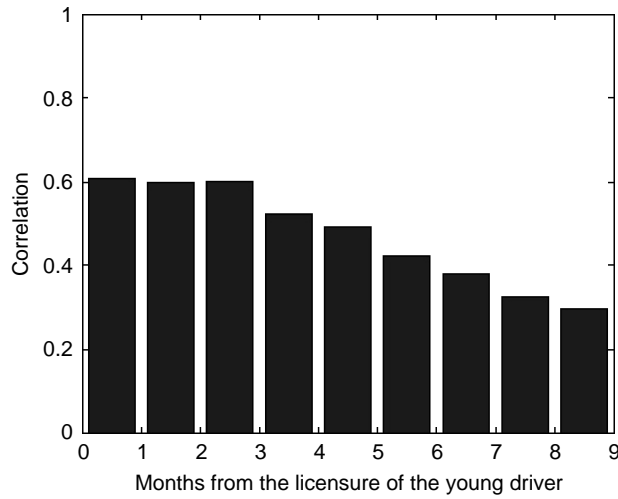
FIGURE 4 Correlation of risk indices for turning maneuvers over time: (a) between male young drivers and fathers, (b) between female young drivers and fathers, (c) between male young drivers and mothers, (d) between female young drivers and mothers, (e) between male young drivers and siblings, and (f) between female young drivers and siblings.



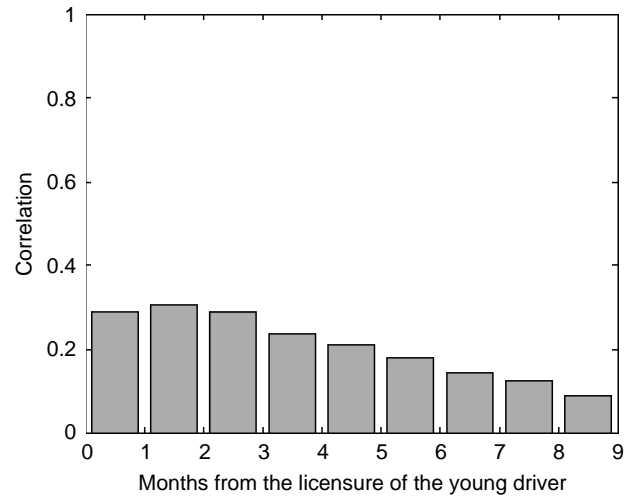
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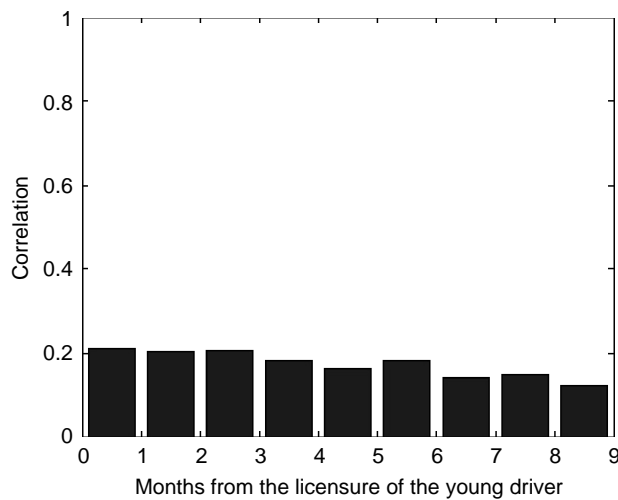
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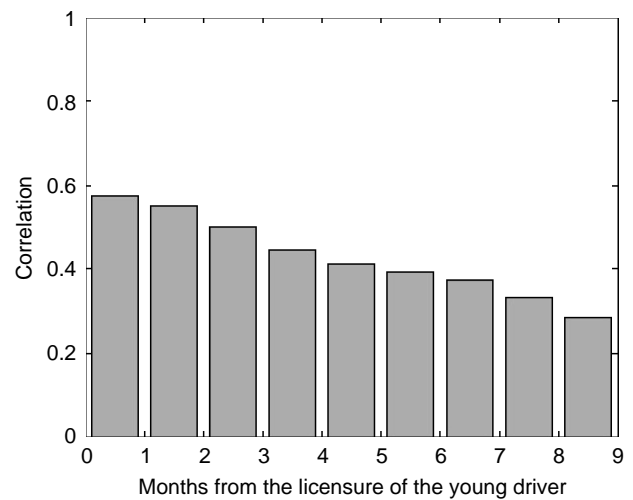
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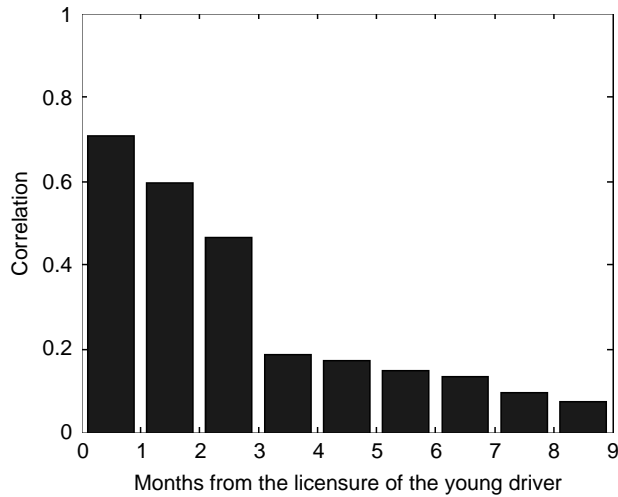


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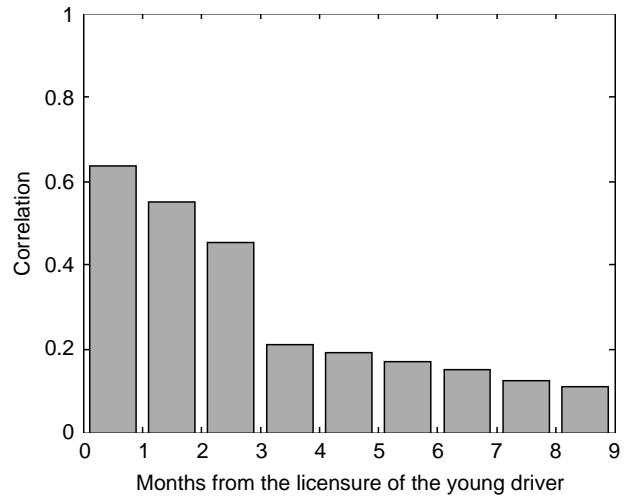


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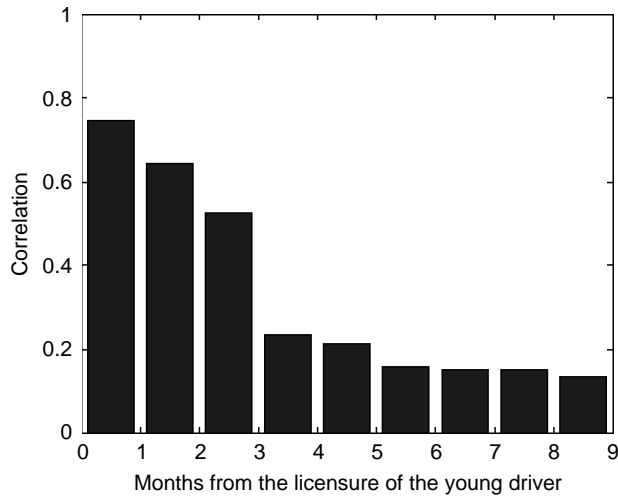
FIGURE 5 Correlation of risk indices for lane-handling maneuvers over time: (a) between male young drivers and fathers, (b) between female young drivers and fathers, (c) between male young drivers and mothers, (d) between female young drivers and mothers, (e) between male young drivers and siblings, and (f) between female young drivers and siblings.



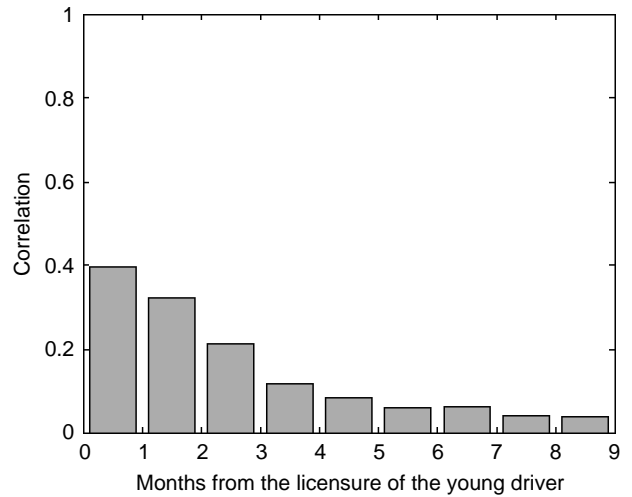
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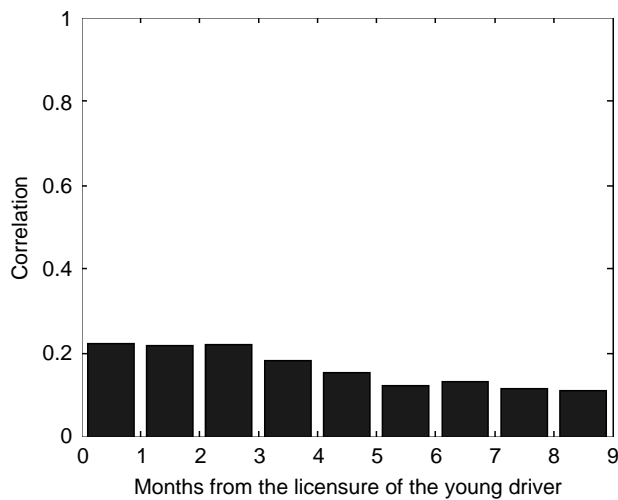
(b)



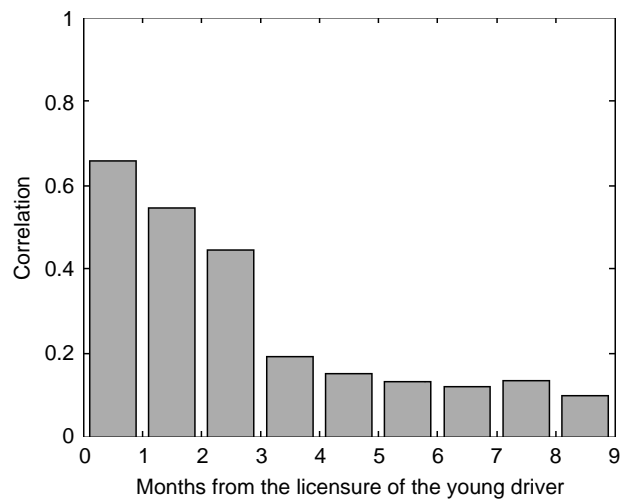
(c)



(d)

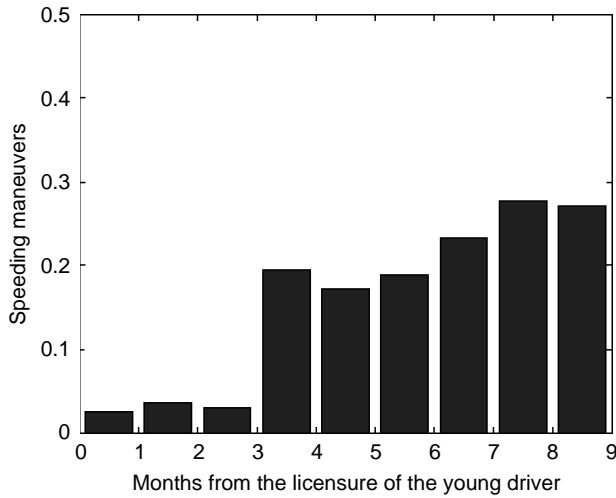


(e)

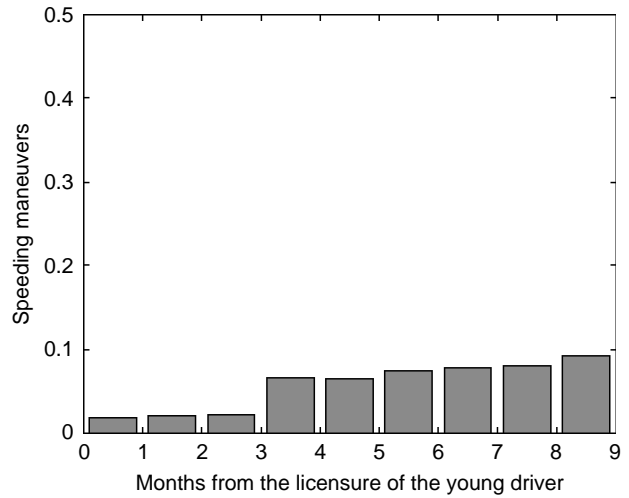


(f)

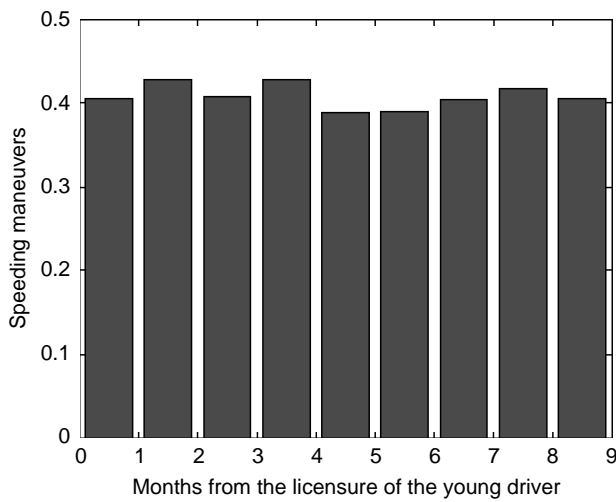
FIGURE 6 Correlation of risk indices for speeding maneuvers over time: (a) between male young drivers and fathers, (b) between female young drivers and fathers, (c) between male young drivers and mothers, (d) between female young drivers and mothers, (e) between male young drivers and siblings, and (f) between female young drivers and siblings.



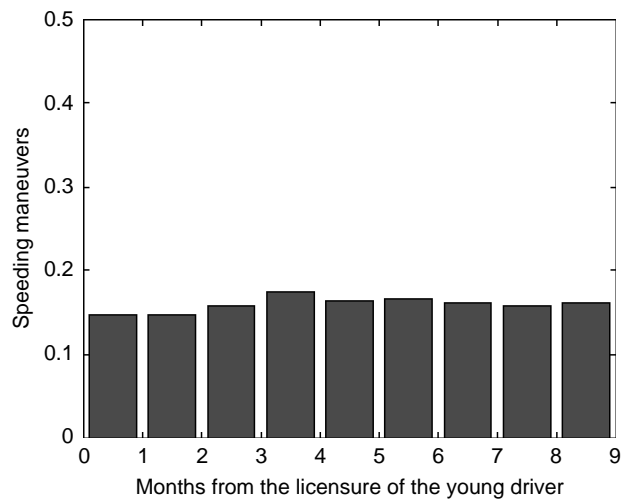
(a)



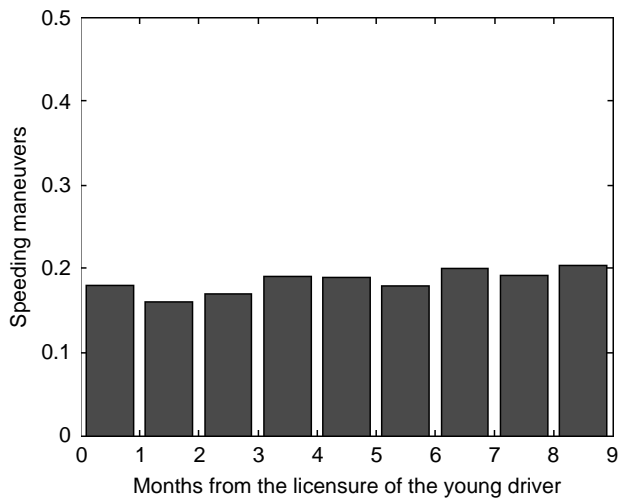
(b)



(c)



(d)



(e)

FIGURE 7 Variation of risk indices for speeding maneuvers over time: (a) for male young drivers, (b) for female young drivers, (c) for fathers of young drivers, (d) for mothers of young drivers, and (e) for siblings of young drivers.

the behavior of the experienced drivers that accompany them. In this period, young drivers are motivated to obtain approval and trust of their parents about their driving abilities, partly to secure access to the family vehicle in the solo driving period. During the following months, the behavior of the young drivers is progressively less correlated to the behavior of their family members. A closer inspection of the driving patterns reveals that this variation is the result of changes in the behavior of the young drivers, which record higher risk indices, especially for male drivers. Presumably, young drivers develop their own driving styles under the effect of social pressure and personality characteristics, but still maintain similarities with their main role models within their families.

The results also provide insight into different components of driving behavior by analyzing the correlations for four different classes of maneuvers. Braking and accelerating maneuvers show higher correlation values, whereas speeding maneuvers show the lowest correlation values and exhibit the steepest decrease in correlations after the transition from accompanied to solo driving. This finding appears logical considering that the correlations drastically decrease when the accompanied period ends, and young drivers are subject to social pressure from their peers and not only to role modeling from their family members.

Overall, the present study clearly indicates the existence of intrafamilial transmission of driving behavior. On the one hand, the careful driving style of parents is a positive model for their offspring and could serve as an inhibitory force on the development of risky styles, especially during the initial accompanied driving period. On the other hand, the decrease over time of the association between the driving behavior of parents and their children indicates that young drivers are influenced not only by their family members but also by other factors not accounted for in the present study, such as peer socialization and personality characteristics. From a policy perspective, these findings indicate a need to carefully consider the role played by parents in the driving education of young adults, not only by giving parents the responsibility for their children's driving, but also by advising parents how to manage this responsibility (7, 8, 10, 11). The results also indicate that the GDL experience has no substantial impact on the behavior of other family members. A challenge for future GDL programs is to influence parents to view them as an opportunity to rethink their own driving behavior and adopt more careful and considerate styles, in part to provide positive modeling for their young drivers.

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