INHIBITORY CONTROL AND REWARD PREDICT RISKY DRIVING IN YOUNG NOVICE DRIVERS: A SIMULATOR STUDY

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Summary: The purpose of our study is to unravel the cognitive mechanisms that underlie risky driving in young novice drivers. Based on the two pillars of the Dual Systems Model of adolescent risk taking, we hypothesized that (1) lower capacity for cognitive control (inhibitory control), (2) a rewarding context, and (3) the interaction of these predict risky driving and constitute part of the cognitive basis for the large number of crashes in the young novice driver population. Two groups different in age (n=31, 17-18 year-olds; n=22, 22-24 year-olds), but equal in driving experience participated in our experiment. Each participant completed two 28km test-drives in a STISIM M400 driving simulator. In the first drive, participants were asked to drive as they normally do. For the second drive, participants were told they could obtain a monetary reward for completing the drive as fast as possible, although for each collision or traffic violation (except speeding), penalty time would be imposed. Inhibitory control was measured by means of a stop signal reaction time task (SSRT). Measures of risky driving included: standard deviation of lateral lane position (SDLP), responses to critical events, speeding, and red light running. We found that: (1) inhibitory control still improves within the young driver population; (2) lowered inhibitory control had a driving specific effect: drivers with lower inhibitory control (SSRT) had a higher SDLP; (3) a rewarding context predicts risky driving as speeding and red light running occurred more often in the trip with than without reward.

OBJECTIVES

Young drivers – a highly risk prone driver population

Compared to other age groups, young drivers are involved in a disproportionately large number of crashes (Kweon & Kockelman, 2002; Evans, 2004, p. 155) and are also mostly responsible for them (Williams & Shabanovab, 2003). Lack of driving experience certainly has a role here (McKnight & McKnight, 2003). However, research in the field of developmental- and cognitive-neuroscience has led us to focus on other potentially important explanatory factors (Yurgelun-Todd, 2007).

The Dual Systems Model of Adolescent Risk-Taking

Adolescence is a period in which the developmental trajectory of cognitive control is diverged from development of the social-emotional system. More specifically, research in the field of developmental cognitive neuroscience has shown that in adolescence: (1) cognitive control is not yet fully developed ; (2) neurobiological changes (for instance changes in the dopaminergic system) lead to higher reward-seeking (Casey, Getz & Galvan., 2008; Steinberg, 2008 & 2010; Crone, 2009). Cognitive control is important for the regulation of complex behavior including performance of appropriate and inhibition of inappropriate actions (e.g. reward-seeking impulses that conflict with long-term plans). Since cognitive control is not fully developed during adolescence, it may be hypothesized this maturational lack of cognitive control represents an explanation, additional to lack of driving experience, for increased risk behaviour in adolescents relative to adults. In addition, in rewarding contexts, adolescents could be especially prone to risk taking behavior given that their developing cognitive control cannot inhibit their increased reward-seeking impulses.

Implications of the Dual Systems Model for Driving Behavior

The first study showing evidence for increased risky driving in adolescents versus adults when the social-emotional system is triggered used a driving video game (Gardner & Steinberg, 2005). A stronger increase in risky driving was shown in adolescents than adults when participants played the game in the presence of peers. However, no tests of cognitive control were conducted to verify the suggested developmental differences in cognitive control between adolescents and adults. A recent study has correlated specific measures of cognitive control (i.e., mental shifting, working memory updating and response inhibition) and driving performance (Mäntylä, Karlsson & Marklund, 2009). As a measure of driving performance, lateral deviation from optimal driving lines was measured in a lane change task. In this study a pc-based low-fidelity setting was used that only required steering (i.e. no other driving operations were included in the simulation) and age effects were not studied. Other recent studies attempted to go beyond correlation and demonstrate a causal connection between cognitive control and driving performance (i.e., lateral lane position) using the disinhibiting effects of alcohol (Fillmore, Blackburn, & Harrison, 2008) and prefrontal trans-cranial brain stimulation (Beeli, Koenke, Gasser & Jancke 2008). Age effects were not studied here either. In summary, to the best of our knowledge, the driving specific implications of the described adolescent developmental factors have not been tested together yet in a factorial design, on a high-fidelity simulator, using different age-groups.

Hypotheses

Based on the two pillars of the Dual Systems Model of adolescent risk taking, we hypothesize that (1) lower capacity for cognitive control, (2) a rewarding context, and (3) the interaction of these predict risky driving and constitutes part of the neurocognitive basis for the large number of crashes in the young driver population.

METHODS

Participants

Fifty-three young drivers were recruited using three inclusion criteria: (1) age between 17-18 years or 22-24 years, (2) a (full or provisional) driving license, (3) no more than two years driving experience at the time of testing. Participants were not paid but entered a draw for monetary rewards (20, 40, or 60 Euros; see also ‘reward manipulation’ section). All participants gave informed consent; had normal/corrected-to-normal vision and none suffered from simulator sickness. Participants were divided into two groups based on their age (n=31, mean age 17.9 years, 21 men; n=22, mean age 22.6 years, 15 men). These groups were matched in terms of gender ratios and driving experience (i.e., a third of each group were provisionally licensed novice drivers, and there was no statistically significant difference in the amount of self-reported driving done by the 17-18 year-olds (5411 km/year) and the 22-24 year-olds (5316 km/year); $F(1,51) < 1$, $p = .096$). In the analyses of red light running, six participants' (two 17-18 year-olds, four 22-24 year-olds) data fell outside the tripled inter-quartile range and were excluded from the analyses as outliers.

Driving simulator

The experiment was conducted on a fix-based STISIM M400 driving simulator (System Technology Inc. Hawthorne, CA) with a force-feedback steering wheel, an instrumented dashboard, brake and accelerator pedals. The visual environment was presented on three computer screens (each with 1280 x 800 pixels resolution and 60Hz refresh rate) with rear view and side-view mirror images. Data were collected at frame rate.

Stop signal paradigm

As a standard laboratory measure of response inhibition (and thus cognitive control), the stop signal paradigm was used (Logan & Cowan, 1984; for a review, see: Verbruggen & Logan, 2008). This task included two practice sessions (40 trials each) and one experimental session (96 trials). In each of the sessions, a two-choice reaction time task was used requiring participants to press a button (left or right) in response to a stimulus (an 'X' or an 'O') presented centrally on screen. In each trial after 1000 ms, a fixation cross was presented for 500 ms. Then the stimuli were presented for 1000 ms and required a response between 150-1000 ms after onset. This first practice session served to determine the individual speed level for each participant, to be used as a reference in the second practice and experimental session. In the second practice and experimental session, in the same two-choice reaction time task on a randomly selected 25% of the trials, an auditory stimulus (1000 Hz, 70 dB, 100 ms) was presented in addition to the visual primary-task stimulus. Presentation of this tone designated that the subject was to refrain from responding to the stimulus on that trial. Importantly, the time interval between the stimulus and the stop-signal was initially set 50 ms below participants' individual speed level. Subsequently the interval varied dynamically according to a staircase tracking algorithm, to converge on a stop-signal delay at which the probability of stopping is 50%. Stop-signal delay was increased by 50 ms if the response was withheld and decreased by 50 ms when it was not.

Scenarios

The Simulated Driving Task consisted of two practice sessions that served as a warm-up and two experimental sessions. The scenario presented in the experimental sessions was a 28 kilometer daylight driving scenario on a two-lane road with bidirectional traffic, including both inner- and outer-city sections with a speed limit of 50 and 90 km/hour respectively. Twelve critical events were presented (e.g., a pedestrian crossing the road, a car suddenly appearing from behind a building and pulling back at the street). Critical events were calibrated such that crashes could be avoided by braking (when driving at speed limit) or steering around the obstacle. Apart from the critical events, other vehicles were presented on the roadway at random intervals but required no passing or braking on the part of the driver. In the scenario, participants had to drive through 18 intersections equipped with traffic lights (red n=10; green n=4; yellow n=4 in randomized order).

Reward manipulation

For the first trip, participants were instructed to drive as they would normally do. For the second trip, response conflict was introduced by providing monetary reinforcement for quickly completing the drive, but also for driving safely and not making any violations (i.e., stopping at a red light, not crossing a full line) or collisions (Fillmore et al., 2008). It was explained that participants could increase their chances of earning money by completing the trip in the shortest finish time, but for each violation (except speeding) or collision, one minute of penalty time would be imposed. To provide a point of reference, participants were informed that this trip was of similar length as the first trip and they were told their finish time of the first trip. Travel time was projected on screen during the second trip. In line with Fillmore et al (2008), we chose not to balance the order and always presented the trip without reward first.

Data collection and analysis

Stop signal reaction time (SSRT). The SSRT was calculated by subtracting the stop signal delay from the reaction time (Verbruggen & Logan, 2008). The shorter the SSRT, the higher inhibitory control is thought to be. To determine if the two groups were different in terms of response inhibition, SSRT was analyzed in an ANOVA with age as between-subjects factor.

Risky driving behavior. Measures of risky driving included responses to critical events (number of collisions), speeding (percentage of total distance above the speed limit), red light running (number of times), and standard deviation of lateral lane position (SDLP). SDLP is a sensitive measure of driver impairment for example due to increased mental workload and various drugs (De Waard, 1996; Ramaekers, 2003). SDLP was also found to be a reliable characteristic of an individual’s normal driving behavior; test-retest reliability measured from young and middle-aged individuals are generally higher than r=0.75 (O’hanlon JF, Brookhuis K, Louwerens J, 1986). In the computation of SDLP, segments associated with lane changes were excluded. A multivariate analysis of variance (MANOVA) was conducted first to provide an overall measure of driver performance as a function of experimental conditions. Univariate statistical analyses were then carried out by entering the different measures of risky driving behavior as dependent measures into four separate repeated measures ANOVAs with within-subjects factor reward (2: no, yes), between-subjects factor age (2: 17-18 year-olds, 22-24 year-olds), and SSRT as a continuous predictor variable.

RESULTS

Inhibition

SSRT was significantly lower in the 22-24 year-olds (m=209ms; SD=37ms) than in the 17-18 year-olds (m=230ms; SD=25) (F(1, 51) = 4.860, p=.032) indicating that basic cognitive control (i.e. inhibitory control) still improves within the young driver population.

Risk Behavior

Results are presented in Table 1. The MANOVA revealed a main effect of Inhibition (F(4, 41) = 2.9, p = .03) and Reward (F(4, 41) = 16.5, p<.001) (all other F-values <= 1, p-values > .41).

Response to critical events. Although the number of critical events resulting in collisions was higher in 17-18 year-olds than 22-24 year-olds without and with rewards, there were no significant main or interaction effects for the critical events.

Standard Deviation of Lateral Lane Position (SDLP). There was no difference between the 17-18 year-olds and 22-24 year-olds in SDLP without or with reward. Importantly, there was a main effect of inhibition. A correlation analysis between the measure of inhibition (SSRT) and SDLP indicated that with increased inhibitory control there was a decrease in SDLP (r=.443, p=.001). Unexpectedly, SDLP was smaller in the ride with than without the reward.

Speeding. The percentage of total distance drivers were speeding was higher in 17-18 year-olds than 22-24 year-olds without and with rewards, but the main effect of age was only marginally significant. In addition, following our expectations, speeding increased when participants were offered a reward relative to no reward (57.5 versus 39.6).

Red light running. Although red light running was more common in 17-18 year-olds than 22-24 year-olds in the ride without reward it was similar in the ride with reward. There was however no main effect of age or an interaction of age and reward. Following our expectations, red light running increased when participants were offered a reward relative to no reward (.68 versus .15).

Table 1. Means (m) and standard errors (SE) of risky driving behavior by age group and reward condition, and univariate statistical effects

	No reward		Reward		Effects				
	17-18 yr	22-24 yr	17-18 yr	22-24 yr	inhibition	reward	age	inh. x rew.	age x rew.
SDLP (meters)	m=.294	m=.292	m=.279	m=.256	F=9.9	F=10.1	F<1	F<1	F=1.64
	SE=.013	SE=.016	SE=.011	SE=.014	p=.003	p=.003	p=.49	p=.48	p=0.21
Speeding (% of distance)	m=44,5	m=34,7	m=61.9	m=53.2	F<1	F=33.3	F=2.9	F<1	F<1
	SE=4.43	SE=5.3	SE=3.43	SE=4.1	p=.81	p<.001	p=.095	p=.48	p=.87
Red light running (# of times)	m=.31	m=0	m=.67	m=.70	F<1	F=11.4	F<1	F<1	F=1.1
	SE=.09	SE=.12	SE=.18	SE=.23	p=.61	p=.002	p=.39	p=.73	p=.30
Critical events (# of accidents)	m=5.8	m=4.7	m=5.6	m=4.7	F=1.26	F<1	F=2.15	F=1.12	F<1
	SE=.46	SE=.55	SE=.55	SE=.66	p=.27	p=.77	p=.15	p=.29	p=.80

*significant effects in bold

CONCLUSION

The results show that inhibitory control still improves beyond the age of 18. Although improvements were demonstrated on various measures of inhibitory control (e.g. stroop-, antisaccade-task) in the field of cognitive neuroscience, to the best of our knowledge these improvements were not demonstrated to extend beyond 18 years (Bunge & Crone, 2009).

In line with our hypothesis that lower capacity for cognitive control predicts risky driving, lowered inhibitory control had a driving specific effect: young drivers with lower inhibitory control (SSRT) drove with higher SDLP. Mäntylä et al. also studied the relationship between driving performance (i.e. lane change accuracy) and cognitive control but only found a significant overall correlation between driving performance and 'working memory updating' – another component of cognitive control. The difference between their and our results might be due to the fact that they used a rudimentary lane changing task in a low-fidelity setting that required no other driving operations than from maneuvering the steering wheel whereas here a more complete driving scenario was implemented on a high-fidelity simulator.

The results also showed support for our hypothesis that a rewarding context predicts risky driving since speeding and red light running occurred more often in the trip with than without reward. Congruently, Gardner & Steinberg found that peer-presence (i.e., a potential source of reward) leads to increased risk taking in a driving context (Gardner & Steinberg, 2005). However they only studied red-light-running behavior and did so in a highly simplified video game where participants could only control a single response key to activate the brakes of a car that they saw from a third-person view. Our findings thus add to the existing literature by showing the effect of a monetary reward (versus peer presence), including different types of risk behavior, and using a more realistic setting in a high fidelity simulator. The unexpected effect of reward on SDLP might be the result of a learning effect due to not balancing the order of trips across subjects. This part of the procedure was derived from Fillmore et al. (2008) that always presented the trip with reward as second trip. Although not significant, their results show a similar decrease of SDLP in the second trip.

With regard to the hypothesized interaction between reward and inhibitory control, the effects of reward on risky driving behavior were not further modified by our measure of inhibitory control. Fillmore et al. (2008) showed that an increase in SDLP in a session with (vs. without) alcohol was even more pronounced when a reward was offered and concluded that this was due to the disinhibitory effect of alcohol. Possibly variance in inhibitory control in our study was not large enough for such an interaction to occur. Unfortunately Fillmore et al. used another measure of inhibition which complicates a direct comparison of our inhibition effects. As inhibitory control increases linearly with aging (Casey et al., 2008), a comparison of age ranges within adolescence that are further apart probably would increase between-group differences in inhibition. However, selection of age ranges in the present study was limited by licensing age, which is 17 in Belgium. Still we might increase the difference by solely selecting 17 year-olds in the youngest group. An alternative strategy might be to include different measures of inhibition as measures might differ in terms of sensitivity. However, future research is necessary to resolve these issues.

Applications. Recent research has shown that cognitive control functions are flexible and can be trained, leading to improvements in performance (Cassavaugh & Kramer, 2009). To date, driver training or interventions could not be designed to target exact neurocognitive mechanisms. By pinpointing the cognitive and affective mechanisms of risky driving behavior (i.e. the role of inhibitory control and rewards), these can become specific targets of improvement in future driver training programs aimed at safe driving and the decrease of fatalities.

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