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Understanding adolescent development: Implications for driving safety

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Abstract

Problem: The implementation of Graduated Driver Licensing (GDL) programs has significantly improved the crash and fatality rates of novice teen drivers, but these rates remain unacceptably high. *Method:* A review of adolescent development research was undertaken to identify potential areas of improvement. *Results:* Research support for GDL was found to be strong, particularly regarding early acquisition of expertise in driving safety (beyond driving skill), and to limitations that reduce opportunities for distraction. GDL regimes are highly variable, and no US jurisdictions have implemented optimal regimes. *Summary:* Expanding and improving GDL to enhance acquisition of expertise and self-regulation are indicated for implementation and for applied research. Driver training that effectively incorporates safety goals along with driving skill is another target. *Impact on Industry:* The insurance industry will benefit from further GDL enhancements. Benefits may accrue to improved driver training, improved simulation devices during training, and automated safety feedback instrumentation.

Keywords: Adolescence; Development; Teen driving; Expertise; Self-regulation

A recent resurgence of research in adolescent development has arisen for many reasons, but perhaps most significantly because of new tools for studying how adolescents make the critical transition from childhood to adulthood (Lerner & Steinberg, 2004). Most notably, advances in neuroimaging have opened a novel terrain for exploring and understanding how the adolescent brain begins to change dramatically at around 11 years of age or so, and continues to develop structurally and functionally well into the third decade of life, with detectable impacts on cognitive, emotional, and social domains summarized in recent reviews (Keating, 2004; Steinberg et al., 2006). Less noticed in the public discourse, but with similar impact on our understanding of adolescent development, have been advances in other research tools. Some of these are methodological, such as experience sampling methods (ESM) that use hand-held remote devices (cell phones, pagers, personal digital assistants) to capture on-line, in-context self-reports of adolescents' behavior and mood. Others have focused on new analytic models, such as rapidly expanding approaches to the understanding of developmental trajectories, growth curves, and latent classes or types of transitions through adolescence.

As a consequence of these technical, methodological, and analytic advances, our understanding of adolescent behavior has become more robust and nuanced, but also more complex. It is sufficiently complex that the proffered title for this paper, "What makes teens tick?" asks a question beyond our current scientific capabilities, or at least mine. A few general observations drawn from an expanding research literature illustrate the complexity that a moderately comprehensive answer would entail (Steinberg et al., 2006). The pathways through which adolescents arrive at positive outcomes of health, mental health, achievement, and social competence, or conversely encounter significant problems in one or more domains, are both multifaceted and responsive to a wide range of contextual factors. In addition, it is important to note that not only do contexts impact the patterns of adolescent development, but that adolescents in turn impact the contexts in which they are developing, through increasing opportunities for selection and shaping of the contexts in which they find themselves.

The patterns of inter-individual differences are thus clearly complex, but so are intra-individual patterns of mood, self-

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regard, emotional responses to personal relationships, and so on, across weeks, days, even hours. Most people, especially parents of adolescents, would not likely be surprised at this description of variability among different adolescents and within individual adolescents. Our increased ability to capture and study this variability – one might be inclined to think of it as volatility – presents both a challenge to our standard models of adolescent development, but also an opportunity to understand adolescence from a more grounded, and thus valid, perspective.

But if this seems complex to those of us who study adolescent development, imagine for a moment what a challenge it seems to adolescents who are attempting to navigate this transition in contemporary society. The exponential expansion in modern society of "possible selves," each of which is rapidly and strongly supported by a commercial media network that grows virally with the emergence of any new trend (Roberts, Henriksen, & Foehr, 2004); the virtual explosion of technology-supported social interconnectivity that puts in doubt many of our traditional assumptions about how peer groups are constituted and function (Brown, 2004); the rising bar of cognitive complexity that is required to succeed in an information age, along with the increasing penalties for not keeping up (the "elite versus the McJobs" phenomenon; Keating, 1998) – to name just a few challenges to the modern adolescent – present novel demands for identity development, social development, and the development of meaningful competence.

This descriptive overview is not intended to minimize the struggles of earlier generations of adolescents who confronted privation, depression, world wars, and other dramatic challenges to becoming a successful adult. What the increasing complexity of the modern world generates, whether observed by the researcher from the outside or experienced by the adolescent from the inside, is a massive set of demands for self-regulation and self-governance. The specific character of this new set of demands, which we can call for convenience "complexity management," relates in a fundamental way to some of the most intriguing new findings in the field of adolescent development.

The core of this emerging picture is focused on developments in the prefrontal cortex (PFC), including the connections between the PFC and other brain areas such that we might more appropriately refer to as a PFC-system. During adolescence, there is greater relative growth of this PFC-system compared with other features of brain development during this same period, with the growth of this system during other developmental periods, or with patterns of brain growth in non-human primates.

In addition to this significant pattern of structural change, the PFC-system appears also to be central to changes in cognitive, emotional, social, and behavioral functions during adolescence (Keating, 2004; Steinberg et al., 2006). The structural and functional implications are numerous and far from fully understood, but a key organizing theme for many of these changes is that the PFC-system is assuming a "governance" or "management" function, a function that appears to gradually come under greater conscious control over the period of adolescence and young adulthood (Keating, 2004).

Compounding this picture, however, is the recognition that many other changes are happening at the same time, and there is no guarantee of synchrony among these changes. Some of these are internal to the organism, including a surge of appetitive drives, including but not limited to hormonally-based increases in sexual interest that are partly set in motion by pubertal changes. Some are external to the organism, such as a shift toward peers as a primary source of input for identity, behavior, and social issues, and a concomitant decrease of parental scaffolding of behavior, both of which are related to a greater freedom of movement and decision-making. The potential for harmful asynchronies across these domains of development, especially given the relatively more rapid emergence of new passions combined with the relatively slower pace of the self-regulatory, self-governance role of the PFC-system, which we have described metaphorically as "a situation in which one is starting an engine without yet having a skilled driver" (Steinberg et al., 2006, p. 721) – a metaphor that seems particularly apt given the topic of our present discussion. Interesting direct evidence for this particular asynchrony was reported in a recent event-related functional magnetic resonance imaging (fMRI) study of children, adolescents, and adults (Galvan et al., 2006), which concluded that:

> *Accumbens activity in adolescents looked like that of adults in both extent of activity and sensitivity to reward values, although the magnitude of activity was exaggerated. In contrast, the extent of orbital frontal cortex activity in adolescents looked more like that of children than adults, with less focal patterns of activity. These findings suggest that maturing subcortical systems become disproportionately activated relative to later maturing top–down control systems, biasing the adolescent's action toward immediate over long-term gains. (p. 6885).*

Translating this new knowledge into advances in policy and practice will likely be neither straightforward nor obvious in all cases. With respect to the topic at hand, reducing rates of crashes, injuries, and fatalities among teenage drivers, the challenge is even greater. This area of applied research has long been concerned with issues of adolescent development, and has incorporated much of our knowledge about this developmental period into policy and prevention efforts (Senserrick, 2006; Shope, 2006; Williams, 2006; Winston & Senserrick, 2006). Also owing to the long and increasingly successful history of applied developmental science in this area, the probability of identifying approaches that have not been at least considered previously is small, perhaps vanishingly so.

Having noted this, it could be that I need not go into further detail. I would argue, however, that there are productive reasons to consider more closely what we are currently learning about adolescent development, even if the topics

are, in general, not new to researchers of teen driver safety. First, as I will review below, the emerging knowledge base provides even stronger support for many of the most successful and most promising approaches to enhancing teen driving safety, by elucidating their grounding in more basic and better understood mechanisms of adolescent development. As discussed later in this paper, further solid grounding may be helpful in keeping up the momentum to implement policies that have been shown to be effective. Legislative changes require continuous efforts, especially when safety exists in a trade-off with custom and convenience, as it so often does (Gillan, 2006). Second, although most of the approaches we might consider have been previously entertained, only a small proportion of them have been evaluated in such a way as to establish a solid evidence base for large scale implementation. Again, understanding the underlying mechanisms of adolescent development could provide an impetus for closer study of approaches that have not been systematically tested, as well as some guidance on how such approaches might be more precisely focused. Finally, a consideration of current research on adolescent development may generate some novel approaches, especially in response to emerging changes in the social contexts of teen driving.

Accordingly, following this introduction, the balance of the paper focuses on important domains of adolescent development, with greatest attention to those areas that may be most relevant to teen driving safety. This research overview is integrated with a consideration of the most significant implications of that work for policy and practice in teen driving safety.

1. Overview

It is clear from a number of recent summaries focusing on the enhancement of teen driving safety and the potential for further harm reduction that there are many possible reasons for continuing high crash and fatality rates among teen drivers, helpfully collected in a recent issue of *Injury Prevention* (Winston & Senserrick, 2006). As noted by Williams (2006), a number of approaches have been tried and evaluated, yielding an emerging picture of what works, but also indicating that there are a number of intriguing ideas that have been only partially tested, or not evaluated in any significant way. It makes sense to begin with the most effective building block identified to date, graduated driver licensing (GDL; Shope, 2007), and to consider the likely mechanisms of adolescent development underlying its success as well as possibilities for extending and enhancing that evidence-based approach.

Before turning to the specifics of that review, a key element of the conceptual framework guiding much of the current work on adolescent development is worth emphasizing, because it bears on some continuing controversies in the teen driving safety literature that a number of observers have identified. The essential point is that aspects of adolescent development – including developmental dynamics within the individual, how that individual interacts with the contexts of everyday life, and how the collective dynamics of adolescent groups function – do not operate independently of each other. In other words, isolating single characteristics to identify the proverbial "silver bullet" is a research and policy strategy that is doomed before it begins. What is needed is a strategy that maximizes the potentially beneficial interactions among multiple dimensions that contribute to increased safety and harm reduction.

One version of an unproductive dichotomy analyzed by Senserrick (2006) is that between two targets of intervention, " . . . underdeveloped skills due to inexperience – 'the young driver problem' – or intentional risk taking associated with adolescence – 'the problem young driver'" (p. 56). As noted in that review, these contributions are of course not mutually exclusive. Moreover, not only are there a number of additional contributing factors, but these factors likely interact with each other. In short, the relevant aspects of adolescent development for driving safety are multidimensional, the potential contributing factors to elevated rates of collision, injury, and fatality are also multidimensional, thus requiring that the policy and practice response be similarly multidimensional.

2. Graduated Driver Licensing (GDL)

Clearly, the strongest evidence-based policy intervention to reduce teen crashes, injuries, and fatalities has been the introduction of graduated driver licensing (GDL) programs (Chen, Baker, & Li, 2006; Morrisey, Grabowski, Dee, & Campbell, 2006; Shope, 2007; Williams, 2006). These have gradually been extended throughout the United States, and operate in similar fashion internationally. The most recent U. S. survey of the application of GDL regimes in the 50 states (plus the District of Columbia), as of January 2007, is shown in Table 1. A brief overview of how the specific

Table 1
U. S. Licensing systems for young drivers

Restriction	Criterion
Learner's holding period	2 points for >6 mo.; 1 point for 3 – 5 mo.; none for <3 mo.
Practice driving certification	1 point for >30 hr.; none for less than 30 hr.
Night driving restriction	2 points for 9 or 10 p.m. 1 point for after 10 p.m.
Passenger restriction	2 points for <1 underage passenger; 1 for 2 passengers; none for 3; where supervising driver may be <21, point values were determined including the supervising driver as a passenger
Driver education	Where completion of driver education changed a requirement, point values were determined for the driver education track
Duration of restrictions	1 point if difference between minimum unrestricted license age and minimum intermediate license age is 12 or more months; night driving and passenger restrictions were valued independently

Source: Insurance Institute for Highway Safety, *U. S. Licensing Systems for Young Drivers (Laws as of January 2007).*
Note: A score of 6 is defined as a "good" Graduated Driver Licensing regime in this scoring system.

restrictions reflect our current understanding of adolescent development reinforces the validity of such regimes by grounding them in identifiable underlying mechanisms. Such an overview may also point toward potentially productive avenues for enhancing GDL regimes.

Before turning to this overview, however, it is worth noting that a first order of business from a public health perspective would be to apply the most efficacious GDL regime across all jurisdictions. As noted in Table 1, a score of 6 (of a possible 8 points) was rated as a "good" GDL regime. Only 53% of jurisdictions (26 of 51) met this criterion. Moreover, "No state has an optimal graduated licensing system" (Insurance Institute for Highway Safety, 2007, p. 1).

There is sound evidence that effectiveness in reducing crash fatalities is associated with having a sufficient number of active components of the GDL regime (Chen, Baker et al., 2006). The reduction of crash fatalities was about 20% with five or more (out of 7) active GDL components in their analysis, but was non-significant with fewer elements. Two other features of this national evaluation can be noted. First, the same effects were not observed for older novice drivers (20 – 24 or 25 – 29 years of age), suggesting that age as well as inexperience and other features of adolescent development plays a role. Second, the analysis highlights the importance of both nighttime and passenger restrictions (Chen, Durbin, Elliott, Senserrick, & Winston, 2006).

A precise estimate of the public health benefits arising from extension of "best-practice" GDL regimes to all jurisdictions, or expansion of those regimes to include additional restrictions would be difficult, given that the evidence for GDL has not been fully analyzed by its individually active components (an unlikely prospect given that it can only be examined quasi-experimentally in context, but not under full experimental control). Nevertheless, the available evidence strongly supports the conclusion that the overall impact would likely be dramatic. Although the legal and political obstacles are non-trivial (Gillan, 2006), clearly there is nothing on the horizon as promising as extension of optimal GDL regimes to every jurisdiction in terms of immediate public health impact. The basis for this claim is in the growing body of evidence for effectiveness of GDL (Chen, Baker et al., 2006; Morrisey et al., 2006; Shope, 2007; Williams, 2006), but also, as described below, its close fit with important findings in adolescent development.

The specific restrictions assessed in Table 1 can be grouped into categories based on our current understanding of adolescent development. Within each category, possible enhancements of GDL within each of these categories can be considered. It is also important to note again that the components are likely interactive in their effects; for example, the presence of teenage passengers likely interacts with driving at night, when both fatigue and lack of expertise in discerning upcoming hazards place teen drivers at elevated risk, maximizing the negative impact of distractions.

3. Domains of adolescent development

3.1. Cognitive capacity

Potential sources of difficulty for the adolescent driver could lie in the comprehension of important aspects of safety, risk, or long-term consequences of driving behavior; greater difficulty in learning and applying core driving skills; or greater limitations in terms of cognitive processing capabilities. Many elements of traditional driver education have been directed at increasing adolescent grasp of key knowledge about driving and the acquisition of core vehicle management skills. Increasingly, the understanding of underlying mechanisms suggests that this is not likely to be a fruitful approach (Keating, 2004), at least in isolation. In terms of the cognitive appreciation of core concepts, there is no solid evidence to believe that adolescents are at a particular disadvantage. Perhaps unsurprisingly, then, the evidence for the efficacy of traditional driver education in reducing crash or fatality risk has not been forthcoming (Williams, 2006). There is nothing in either research literature to suggest that adolescents cognitively grasp the concepts of risk and safety significantly more poorly than adults, although adults may have some advantage in the precise estimate of risks (Millstein & Halpern-Felsher, 2002a,b). The focus of the risk judgment may have strong influences on whether adolescents are seen to be lacking. Reyna and Farley (2006) propose to resolve the dilemma by acknowledging roughly equivalent analytic skills in judging risk, but decidedly weaker performance by adolescents when they make gist-based, socially derived intuitive judgments. A key goal of future research would be to identify any specific areas in which core cognitive capabilities were sufficiently different between adolescents and adults within the specific domain of driving safety to suspect that their remediation would improve the primary outcomes of crashes, injuries, and fatalities.

3.2. Expertise

A potentially more promising line of inquiry falls under the general heading of cognition and capabilities, but takes an approach that does not focus on core immaturity. The study of expertise and its acquisition had its origin in the study of highly skilled knowledge or performance domains (chess, music, medical diagnosis) but has more recently addressed itself to topics in high level psychomotor performance (Ericsson, 2005, 2006). Although inexperience and lack of expertise are co-extensive concepts to a degree, it is not the case that experience and expertise are the same thing. The research literature on expertise is potentially highly informative for enhancing teen driving safety, and thus merits some further exploration of its key components.

Although some early work on the development of expertise was designed to find alternate explanations for presumed core cognitive differences associated with development, the

rapidly expanding literature on expertise is not solely a methodological challenge to traditional models. Rather, it represents a different approach to understanding cognitive development (Chi, Glaser, & Rees, 1982; Chi, Hutchinson, & Robin, 1989; Koslowski, 1996; Kuhn, Amsel, & O'Loughlin, 1988). The key argument of this approach is that the acquisition of knowledge and skills in specific domains is the driving force of cognitive development. More knowledge and greater ability to transfer knowledge across domains are the keys to developmental advancement. From this perspective, measures of better reasoning, faster processing, or greater mental capacity are derivative of the core progress in knowledge acquisition.

Almost by definition, the study of expertise and its development is specific to particular knowledge and skill domains. Moreover, the focus is on the acquisition of expertise through experience and practice, rather than on age or developmental differences in themselves. Indeed, the early demonstrations that young experts could outperform older novices were central to the argument from expertise (Chi et al., 1982). Consequently, the focus of this work has not been on developmental changes that are specific to any given developmental period, including adolescence. Nonetheless, interesting and generalizable findings from this work bear on some of the major issues in adolescent cognitive and brain development.

One general trend in the work on expertise has been a growing recognition of the importance of meaningful conceptual frameworks for the building of expertise (Case, 1999; Chi, Slotta, & deLeeuw, 1994). Although one hallmark remains the acquisition of automaticity that affords an ever-increasing range of performance, their interconnections in a conceptual framework are increasingly recognized as a powerful mechanism for conceptual change and expanding expertise. Such work has also "begun to examine such general properties as conceptual coherence and organization, and to postulate the existence of top-down processing and/or some form of reflexive abstraction" (Case, 1999, p. 792). The valuable role that self-explanation plays in the acquisition of expertise seems in accord with this trend.

A second general finding is that the acquisition of proficiency takes time, and that attainment of high levels of expertise requires a very substantial investment of time. Ericsson and Charness (1999), for example, have estimated this duration to be at a minimum of a decade to achieve top-level performance for many tasks in the modern competitive world. Interestingly, this applies to premodern expertise acquisition as well. Walker, Hill, Kaplan, and McMillan (2002) studied lifespan changes in hunting ability among the Ache (a tribal group in Eastern Paraguay), and found that peak success in hunting occurs substantially later than peak strength. "Given that Ache start hunting around the ages of 12 – 15, it takes nearly 30 years for hunters to reach their prime" (p. 652). They also noted the evolutionary implications of this as well: "If hunting was an important economic activity of early hominids, the learning curve for hunting success may partially explain why humans have big brains, long learning periods, and long lifespans" (Walker et al., 2002, p. 654).

Two further aspects of expertise acquisition merit attention, especially in this context. The first is the crucial role of deliberate, effortful, motivated practice (Ericsson, 2002, 2005, 2006; Ericsson & Charness, 1999). In particular, much of this focused effort is concentrated on the remediation of performance errors as a necessary component of becoming proficient at any skill. The second is the deliberate construction of automatized subroutines that enable much more complex performance. Both observations clearly imply the operation of a consciously guided self-regulatory effort.

These aspects of expertise do not operate only at the level of top performance. The operation of metacognitive oversight and metastrategic knowledge contributes substantially to ordinary expertise in many domains.

3.3. Teen driver safety and the acquisition of expertise

From the foregoing account, it is clear that there are important points of connection between the emerging work on the development of expertise and central issues in enhancing the safety of young drivers. Indeed, several key aspects are already embedded in optimal GDL regimes. We can note important correspondences between the research literature on expertise acquisition and important constructs in young driver safety: the role of time; the role of an overarching framework to support a goal of competent, safe driving, which implies in turn a key role for motivation; the role of deliberate, effortful, guided practice that focuses on error remediation; and the automatization of core subroutines as a means of freeing up processing capacity and attention to higher order demands – and as a reserve capacity to address emergent situations on the road. These general principles of time, goals, motivated and effortful practice, and automatizing core routines are characteristic of nearly all domains of expertise acquisition, and charting pathways to the acquisition of such expertise needs also to be developmentally informed so as to optimize the quality of the skilled performance as well as the rate of its acquisition (Keating, 1990).

Time: As already noted, there is clear evidence that the acquisition of any highly complex task that requires skilled performance takes a substantial investment of time. If there are exceptions to this rule, they have not yet been discovered (Ericsson, 2006). Certainly driving competently and safely qualifies as a complex task that requires skilled performance, and we should expect that its acquisition will require a substantial investment of time.

This is evident in the pattern of crash rates for all novice drivers, which are highest in the first 250 miles of independent driving, drop by almost two-thirds in the next 250 miles, and show further sharp drops as independent driving experience increases (Workshop Summary, National Academies). Several of the elements of GDL incorporate this aspect of expertise acquisition, either explicitly or implicitly, such as in length of holding period, duration of restrictions,

and so on. There is of course a balance here between safety on the one hand, and the desire on the part of adolescents and their families to have the benefits of independence, access to employment, and so on, without undue restrictions. The increasing evidence for GDL success weighs heavily on the side of moderate restrictions, and expanding its coverage so as to provide adequate and essential time for the acquisition of expertise for adolescents in all jurisdictions is an important goal for public health.

The goal framework: As noted above, a key element for the acquisition of expertise is that it is guided by an overarching framework within which the process unfolds. This framework focuses efforts and shapes the nature of the outcomes that are achieved. One important source of potential difficulty in this respect is the presence of multiple, and sometimes conflicting goal frameworks. From a public health perspective, competent and safe driving is the goal; from a parental perspective, safety is also key, although mixed perhaps with a goal of reduced dependence for transportation; but for the adolescent, the goal is almost entirely to have independent mobility.

For the adolescent, then, getting sufficient skill to operate the vehicle and meeting as quickly as possible the requirements for independent licensing constitute the desired expertise. This is often associated with peer status, in ways that conflict with the goal of becoming a safe and cautious driver. The influence of peers and the larger culture on how one wants to be perceived is a topic we return to below. But it is clear that public appeals to avoid dangerous driving and its consequences may have an unintended effect of increasing adolescents' perception of themselves as being too skilled a driver to become involved in such problems (Harre, Foster, & O'Neill, 2005). If the goal framework is high skill, rather than high safety, the focus of effort in the acquisition process will not be as aligned with the desired public health outcomes. This mismatch is evident as well in the finding that courses that teach advanced skills, such as skid control, to adolescents, appear to have the iatrogenic effect of inducing unduly optimistic self-perceptions of competence that lead to higher, rather than lower crash rates (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002; Katila, 1996; Williams, 2006).

Efforts to get the goals right may be an essential feature for guiding the acquisition of expertise at skilled, *safe* driving. It is not immediately obvious how to instill this goal in the face of powerful cultural and peer pressures that support a conflicting framework, although a combination of parental scaffolding supported by GDL regulatory regimes (Simons-Morton, Hartos, Leaf, & Preusser, 2006; Simons-Morton & Ouimet, 2006) and social marketing to enhance adolescents' acceptance or endorsement of safe driving as a goal (Harre et al., 2005; Smith, 2006) may offer some promise.

Practice – deliberate, effortful, guided: Obviously, it is not merely elapsed time or accumulation of experience by itself that optimizes progress along the "pathway to expertise" (Keating, 1990). The most prominent feature of effective expertise acquisition is the level of practice that is deliberate, effortful, and guided (Ericsson, 2005, 2006). Clearly, as noted above, this requires motivation toward the goal of expertise acquisition. But that motivation must yield consistent effort, and that effort must be guided so as to focus on the active components of the desired expertise. In turn, this needs to be guided by a careful task analysis so as to structure the practice in a productive way.

Another component of this practice is more problematic from the perspective of increasing teen driver safety. Expertise is never acquired without error. In fact, a focus on the underlying reasons for errors, and how best to remedy them, is central to effective expertise acquisition. But driving errors, especially during independent driving, are potentially extremely costly. The GDL practice driving requirement (see Table 1) is an attempt to address this, although the sharp increase in crash rates as independent drivers has not been reduced by supervised practice driving. There may be ways to enhance the practice driving component to enhance its value. Similarly, there may be some promise in improved off-road simulators and training programs that focus attention on the highest risk road dangers (Fisher, Pollatsek, & Pradhan, 2006; Pollatsek, Narayanaan, Pradhan, & Fisher, 2006). Future research and policy development could productively focus on how to afford novice teen drivers the opportunity to commit, and learn from, errors whose cost is minimized. Adding a restriction on the type of roadways that newly licensed drivers can traverse is one such possibility that is not currently included in most GDL programs, but one that could make early crashes less likely to be severe or fatal.

There is an important example of an interaction among elements of safe driving that arises in the contet of learning from errors. Specifically, what constitutes an error is largely determined by the goal framework one is employing. Consider a case where a potential accident is avoided by a last-second maneuver. From a goal framework of safe driving, this counts as a probable error, feedback from which would include reflection on hazard detection, adequacy of monitoring, and so on. From a goal framework of "skilled" driving, it might be seen as a successful exercise of skilled vehicle control, with no error to be considered and learned from. This confusion of goals – "skill" versus "safety" – contributes both to a detour on the pathway to expertise by misidentifying error-generated learning situations, as well as to potential harmful effects of skill-focused driver training, such as skid control (Katila, 1996). Even further, the "successful" lasts-second maneuver may be emotionally arousing and reinforcing, akin to winning a risky gamble (Husted et al., 2006).

Automaticity of subroutines: When a skill component has become incorporated into a subroutine that subserves a broader skilled performance, we can speak of that component as having been automated. This automaticity is critical for any complex skill, in part because of the relatively fixed capacity that we can devote to conscious focusing and monitoring. Fluent reading requires the automaticity of word

decoding; musical performances presume that attention is not devoted to subskills of hand movements and so on. That automaticity of important components of skilled driving is central to road safety is perhaps self-evident. Senserrick (2006) notes that the difference between having and avoiding a crash is measured in milliseconds, as is the difference between severe and more moderate crashes. This is an interesting inverse aspect of the time/expertise relationship. It takes substantial time investment in order to preserve a few milliseconds in an emergent situation, but it is those few milliseconds gained through more effective hazard detection, more rapid vehicle adjustments, and so on, that are critical.

It is important to note, however, that unsafe habits can be automated as readily as safe ones. Because significant "embedding" of automatic routines is based in the brain (Hill & Schneider, 2006; Posner & Rothbart, 2007), there are significant risks associated with unstructured acquisition of expertise. It is obvious that patterns of speeding or close following do not typically result in crashes, otherwise they would be even more rare. Each "success" of crash avoidance following a dangerous maneuver creates its own seed toward automaticity.

Another important developmental finding is that on some tasks that adolescents perform as successfully as adults, the adolescents may be using more central processing capacity, whereas adults more quickly divert the performance to peripheral and more automated neural circuitry (Luna et al., 2001). In single focus tasks, the difference in underlying neural circuitry may not matter much in practice. But in circumstances, like driving, where there are multiple parallel tasks to attend to, the cumulative load on the central processor may be excessive. Combined with the neuroimaging evidence noted above (Galvan et al., 2006) on the relative immaturity of top-down control systems, the risk of central processing overload is significant. This highlights in striking fashion the necessity of constructing pathways to expertise that move safe driving habits toward automaticity as rapidly as possible, at least in part to preclude the automating of dangerous driving habits that have not, in the beginning, led to crashes.

3.4. Regulatory competence

One of the most intriguing lines of current research on adolescent development focuses on the integrative functions of the prefrontal cortex (PFC), whose growth and development is a central part of brain growth during this developmental period. It is central, as noted above, because it appears to integrate and govern a wide number of neural functions (Keating, 2004). In the present context, a key aspect of integration is the ability of adolescents to deploy the expertise they have acquired in real world situations, *even when there are major distractions*. These distractions can be external (a group of rowdy friends in the car), self-generated (talking on a cell phone while driving), or wholly internal (ruminating on a social slight that occurred at lunch time). Managing to stay on the task of safe driving, with one's best expertise intact, is a significant challenge for all drivers, but is a particular risk for adolescents whose regulatory competence is still being developed. Thus, safe driving is not only a matter of *how well* one drives, but *how* one drives in the real world with all its complexities of multiple contexts.

This ability to function under challenging circumstances can be thought of as regulatory competence, a domain that has begun to receive increasing attention. We have argued (Steinberg et al., 2006) that during the transition from childhood into adolescence, contextual interactions may play a key role in supporting or inhibiting the quality of daily functioning. During this developmental period when arousal activation is high and regulatory competence is not yet fully developed, individuals need the assistance of a structured and supportive context. In concrete terms, adolescents need other individuals and institutions that will enable them to acquire the necessary skills to function well in the most challenging and complex circumstances. This can be achieved in part by facilitating the development of regulatory competence, but also by protecting them from the harmful effects of deficiencies in regulatory skills until these capabilities have matured sufficiently. Concomitantly, this time is particularly risky for young people with little or no contextual support and those with high vulnerability due to regulatory deficiencies.

We can observe these macrosystem influences on the regulation of adolescent risk behavior in a variety of domains, including cigarette tax policy on adolescent tobacco use, the impact of gun-control policies on access to weapons, the effects of condom distribution in school-based health clinics, as well as the impact of graduated driver's licensing policies on automobile accidents. These policies can be viewed as attempts to impose external regulation on individuals whose judgment and regulatory competence is not yet fully mature. One interesting but unstudied question is the relative effectiveness of policies designed to impose regulatory control on adolescents as a means of limiting risk behavior until greater maturity has been attained versus those designed to limit risk behavior by increasing adolescents' regulatory competence (e.g., through educational intervention). This is a general form of the problem of the "problem young driver" versus the "young driver problem" (Senserrick, 2006).

We can conveniently divide our consideration of regulatory competence into features that are more internal, focusing on the individual adolescent's attention and emotion regulation, and those that are more interactive, which can be thought of as social/behavioral regulation, or in a similar vein, as risk management. Note, though, that this is a distinction made for analytic convenience; clearly, these numerous aspects of regulatory competence are deeply and mutually interactive.

Attention and emotion regulation: The task of driving is fraught with many competing demands, all of which operate on a stringent timeline (Senserrick, 2006). Not surprisingly, then, a large proportion of crashes are attributable to

attentional distractions. Maintaining skilled and safe driving, using good judgment in the face of numerous distractions, is a distinct challenge to the available resources of many teen drivers, due to both normative developmental processes and relative inexperience in driving.

Again, these difficulties in attention regulation are to a substantial extent reflected in existing GDL regimes. Perhaps the strongest evidence base for restriction deals with underage passengers in the car during the graduated licensing phase (Simons-Morton, Lerner, & Singer, 2005). This may relate to the truly impressive number of potential distractions associated with adolescent peer groups, including elevating or maintaining one's status by "showing off" risky behavior, by participating in the group conversation, or even by turning aside from the road to speak with passengers, including back seat passengers. Given the pull of peer relations in general, it seems unlikely that one could reliably increase attention regulation strategies on a population basis sufficient to overcome these distractions and thus have a public health impact (Neyens & Boyle, 2007). Thus, the strategy of extending and enhancing GDL regimes seems the best and strongest evidence-based option.

It is a strategy that might productively address other major attentional distractors. One that has received public notice is the use of cell phones while driving. Given how pervasive they are, and the mode and frequency of use by adolescents, this would be an additional GDL restriction well worth further study. Although such a ban might be valuable for all drivers, there may be jurisdictions where a GDL based ban is politically viable but a total ban would not be. By the same logic, the use of other media that are deeply absorbing of attention, such as iPods or other personal music players, DVDs, or the now technologically available live television might well fall under GDL restrictions. The logic is two-fold: with less expertise, novice teen drivers will have greater demands on their central processing resources; and the ability to manage appropriate attentional switching and focusing is likely to be compromised due to immaturity.

Because attention regulation is quite demanding of neural resources, it is susceptible to being compromised physiologically. The most common stressor is sleep deprivation, which is widespread among adolescents, and is implicated as a non-trivial contributor to teen crashes (Groeger, 2006). It is not obvious how to incorporate sleepiness per se into GDL, although night time driving restrictions may indirectly deal with some portion of this excess risk. Given the typical drift in adolescent sleep rhythms to include late nights, however, early weekday mornings may be an equally high risk period.

Not all distractions arise from external sources, however. One key area that has only begun to be researched in adolescent development is that of emotion regulation. There are a number of potential risks to be considered, although emotions associated with driving are not all in the risk category. It is clear that teens have a great desire for the independence that licensing affords, and often experience exuberant feelings at its achievement. Similarly, the positive emotions associated with mastery of a new skill are prevalent. In themselves, there are no particular risks in these; rather, they are completely normative adolescent experiences (Winston & Senserrick, 2006). Where risks arise in this respect, however, they may be expressed in the form of undue optimism about the unlikelihood of crashes for oneself, and about the actual level of one's skill (Harre et al., 2005). Similarly, poorly regulated negative emotions such as anger or fear are likely to compromise safe driving skills, by encouraging driving that is too aggressive or too timid, and by drawing attentional resources away from the primary task.

Although this is true for all drivers, adolescents' developing expertise renders them more vulnerable to these intrusions. As in the case of attention regulation, efforts to directly enhance regulatory competence have a long way to go to have a public health impact through safer driving, but innovative interventions would be a welcome contribution. At a minimum, directly addressing these topics, through simulations, vignettes, and/or role play, may offer some promise. More systematically embedding them in the process of expertise acquisition would be difficult but also potentially rewarding if the right pedagogy could be found.

Self-regulation and the balance of risk: Self-regulation addresses the question of *how* adolescents enact the tasks of safe driving, as different from expertise research, which addresses *how well* adolescents are able to drive. Studying how adolescents interact with others, behave in driving situations, and manage the risks of driving from a perspective of regulatory competence affords the opportunity to survey a very wide range of theoretical and research approaches, but also constrains us to look at this behavior as a delicate balance among competing forces in the lives of adolescents. It is easy but misguided to think of risk taking as one-dimensional with one polarity being "bad" risk-takers who drive recklessly and without forethought, and "good" teens who are cautious and safe drivers. The reality of self-regulation and risk in the context of driving is in reality anything but one dimensional (Harre, 2000), as is true of risk taking in most contexts (Millstein & Halpern-Felsher, 2002a,b; Reyna & Farley, 2006). Thrill seeking ("the problem young driver," Senserrick, 2006) may be one reason that some adolescents take risks, but they also take rational risks because the benefits outweigh the costs, perhaps in some "gist-like" intuitive fashion (Reyna & Farley, 2006) that may often involve status among other teens or a step toward autonomy and independence, to take but two prominent examples.

Harre (2000) generated five "types" of risk approaches among adolescents, which are arrayed on two dimensions: objective crash risk (high or low); and perceived crash risk (high or low). Individuals high on both dimensions may be the classic thrill seekers or those who rationally accept the level of risk as an acceptable cost against some benefit to be obtained. Habitual cautious drivers are low on both dimensions. Those with actual high crash risk but who perceive it to be low have reduced risk perception, while the obverse

pattern as those who are actively risk-avoidant. Of course, contextual circumstances may move an individual's behavior into a different typology: if the benefit is high enough, many adolescents may gravitate toward the "rational" risk-taking type of behavior – that is, they do not effectively regulate their behavior if the reward dimension is too great, an apparently neurodevelopmental characteristic of adolescents (Galvan et al., 2006).

It is important to understand that risk taking is a normal and normative feature of adolescent development (Reyna & Farley, 2006; Winston & Senserrick, 2006). Two lines of approach in policy and prevention present themselves. The first is to help adolescents become more accurate risk "calculators," even if the calculation is often more gist-like than analytic. But how this is approached may make a difference. Social marketing that emphasizes the dramatically negative consequences of risky driving may in fact exacerbate the problem by encouraging misplace optimism about one's own level of skill relative to those portrayed in tragic outcomes (Harre et al., 2005), in much the same way that the teaching of advanced driving skills such as skid control may encourage greater risk taking on the road based on misplaced confidence about how well one can manage difficult driving situations (Hatakka et al., 2002; Williams, 2006).

The second approach deals with a more impulsive kind of risk taking, that arises in situations of social challenge (as in "dare you" games) or of high emotional arousal. These circumstances may overwhelm the judgments of even good risk assessors, if the challenge or arousal is strong enough. One approach may be to try to equip adolescents to resist such inducements, but this is an uphill battle so long as the social context supports "successful" risk taking, that is, where the outcome was success rather than disaster. A more systemic approach would be to shift the underlying cultural assumptions about risky versus cautious driving. Because the social context determines much of the individual's reactions to driving, we can turn to that topic directly.

3.5. Social Relationships

Peers: Are peers, in general, a good or a bad influence on adolescents? As the cliché joke goes, "Yes." As Brown (2004) summarized it in a recent systematic review:

> *The matter is settled, then: Peers are neither an entirely supportive and healthy set of associates for adolescents, nor a social force driving them fervently toward maladaptive outcomes. They have the capacity – if not the inclination – to do both. (p. 389)*

Peers can thus support or undermine perspectives on careful driving. The most immediate risk to safe driving, of course, is the presence of underage passengers being driven by young novices (Simons-Morton et al., 2005). This is one of the most important components of GDL regimes.

The longer term issue, though, is that peers are the primary mediators of the cultural attitudes toward safe driving versus risky driving. The perspective adopted by one's peer group will color everything from the definition of the goal framework, to what kind of practice one chooses to undertake, to how likely one is to deploy regulatory competence in the service of safe driving. Creative efforts to shift the prevailing balance in favor of risky driving toward a different goal framework are clearly needed, and such efforts will need to avoid the glamorization of spectacular failure to be effective (Harre et al., 2005).

Parents: In contrast to much popular belief, the evidence-based reality is that parents remain an important force in the lives of adolescents. Adolescent development "can be understood more fully in the context of relationships with significant others … and relationships with parents remain central to these contexts" (Collins & Laursen, 2004, p. 354). Second only to GDL, the enlistment of parents as the primary supportive context for safe driving has shown the most promise in terms of developing a scalable policy approach to reduce the harm arising from unsafe teen driving. A recent overview by Simons-Morton and Ouimet (2006), based to a significant extent on the contribution of Simons-Morton and his colleagues (Simons-Morton et al., 2006; Williams, Leaf, Simons-Morton, & Hartos, 2006), summarizes the state of the evidence.

The primary approach has been to involve parents of young novice drivers in obtaining compliance with GDL restrictions, whose law enforcement can only be spotty at best owing to resources (Goodwin, Wells, Foss, & Williams, 2006). A key component of this approach is the joint development of a contract between adolescents and their parents, which is soundly based on the evidence that the relationship is the primary active component of parental influence. When combined with incentives (such as insurance discounts), this approach to enhanced compliance effectively enhances GDL coverage without additional legislative restrictions on driving. In addition, because parent-adolescent interactions on this topic may be a source of conflict (Beck, Hartos, & Simons-Morton, 2005), mandated or incentivized parent-adolescent contracts provide a structured and socially approved context within which parents can be empowered to construct scaffolding supports in a cultural context that is otherwise not especially empowering of parental intervention.

Culture and media: Although our ability to discern with confidence the precise effects that the general cultural surround – often communicated through an expanding array of media – have on adolescent development, the balance of evidence supports the claim that "media speak to the unique needs of adolescents when they are highly susceptible to influence from any messages" (Roberts et al., 2004, p.509). As noted above, a good argument could be made that the overwhelming message from the media is that focusing heavily on safe, cautious driving is decidedly "uncool." Designing a social marketing campaign to work against this is a daunting challenge, also as noted above, owing both to the entrenched cultural attitudes and to the potential for

iatrogenic effects when false optimism is unintentionally induced or reinforced (Harre et al., 2005; Smith, 2006; Whittam, Dwyer, Simpson, & Leeming, 2006). The best bulwark against this cultural message would seem to be the evidence-based approaches embodied in GDL regimes, buttressed by increasingly evidence-based parent-adolescent contract programs that add significant weight on the side of compliance.

4. Putting it all together: Theory to practice and back

The notion that successful approaches to the improvement of teen driving safety require comprehensively multidimensional models has been argued effectively from a variety of perspectives. Overviews that help to identify critical dimensions in that multidimensional universe are productive engines for generating new research and policy hypotheses (Berg, 2006; Shope, 2006; Williams, 2006). The overview of new directions in the study of adolescent development is in part an effort to generate such research and policy hypotheses, starting from our growing understanding of core developmental mechanisms in adolescence. Whether it is generative in this fashion remains to be seen.

At another level, the emerging work on adolescent development that focuses on the integrative function of the prefrontal cortex, especially its role in the development of guided expertise, judgment, and regulatory competence in specific contexts, provides further scientific support for many of the most successful current approaches. Their multidimensional nature, which incorporates a number of active components, parallels in significant ways the emerging picture of underlying mechanisms of adolescent development. As noted, the largest immediate advance from a public health perspective would be the extension of GDL regimes to all jurisdictions, the improvement of them toward more optimal sets of restrictions, and their potential expansion through enhanced compliance using parent-adolescent contracts, and possibly through the addition of some new restrictions. As Williams (2006) notes, we have one solidly evidence-based building block in GDL, and it makes policy sense to build on it. The evidence from basic developmental mechanisms in adolescence strongly reinforces that strategy.

The consequences for post-teen driving from this developmental perspective are also worthy of additional thought. To the extent that habitual patterns of reactivity and judgment in the driving situation are being "sculpted" in potentially enduring ways (Hill & Schneider, 2006; Keating, 1998; Posner & Rothbart, 2007), there is added incentive for getting the initial training and expertise acquisition right. Similarly, incorporating strong regulatory competence in the early driving period would likely have a similar salutary effect. Given that adolescence is a potentially sensitive period of development, that is, capable of embedding patterns with a long reach (Keating, 2004), there is the potential for good news: the persistence of good driving habits could lead to lower rates throughout subsequent adult driving careers.

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