



Sensitivity to reward and risky driving, risky decision making, and risky health behaviour: A literature review

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Scott-Parker, B., & Weston, L. (2017). Sensitivity to reward and risky driving, risky decision making, and risky health behaviour: A literature review. *Transportation Research Part F: Traffic Psychology and Behaviour*, 49, 93–109. <https://doi.org/10.1016/j.trf.2017.05.008>
Document Type: Accepted Version

Link to Published Version: <https://doi.org/10.1016/j.trf.2017.05.008>

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Title: Sensitivity to reward and risky driving, risky decision making, and risky health behaviour: A literature review

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Abstract

Young driver road safety has persisted as a global problem for decades, despite copious and diverse intervention. Recently the influence in reward sensitivity, which refers to the individual's personal sensitivity to rewards, has received attention in health-related research, including more generally through decision making in risky circumstances, and in risky driving behaviour specifically. As such, a literature review and synthesis of the literature regarding reward sensitivity in relation to risky driving, risky decision making, and risky health behaviour, with a focus on literature in which adolescents and young adults feature, is timely. Thirty-one papers were identified, and the literature revealed that young drivers with greater reward sensitivity engage in more risky driving behaviours including speeding, crashes and traffic violations; and that individuals with greater reward sensitivity engage in more risky decision making and other risky health-related behaviours (such as drinking and drug use). Adolescents and young adults exhibit heightened sensitivity to rewards in the presence of peers, which has considerable implications for young driver road safety as research consistently demonstrates that carrying peer passengers places all vehicle occupants at greater risk of being involved in a road crash. Consideration of the influence of reward sensitivity in young driver road safety, and other adolescent/young adult health-related safety, appears to be a promising avenue of intervention, with gain-framed messages more likely to be accepted by young drivers with greater reward sensitivity. Future research in jurisdictions other than Australia and Europe will increase our understanding of the influence of reward sensitivity, and exploration of the differential impacts of reward-responsiveness and fun-seeking specifically are warranted.

Keywords

Reward sensitivity; sensitivity to reward; risky behaviour; risky driving; road safety

Sensitivity to reward and risky driving, risky decision making, and risky health behaviour: A literature review

Despite interventions encompassing the three E's of education and training, enforcement, and engineering, young drivers continue to be overrepresented in the road crash fatality and injury statistics. To demonstrate, in Queensland, Australia, young drivers aged 17-24 years comprise 12.6% of the licensed population (DTMR, 2016); however for the 2016 calendar year, persons aged 17-24 years contributed 17.9% of the fatally-injured road users, and 24.7% of the state's fatalities involved a driver aged 17-24 years (DTMR, 2017). Similarly, in the United Kingdom road deaths account for 0.5% of all deaths, but 25% of deaths amongst 15-19 year old drivers and their passengers (Box & Wengraf, 2013). Interestingly, in Australia, as in other countries like the United Kingdom, in recent years there has been a notable reduction in the overall road toll (eg. DTMR, 2013). Notwithstanding this, the proportion of fatalities involving young drivers appears to be relatively constant, and indeed the proportion of life-threatening injuries sustained by adolescents and young adults in road crashes is increasing, particularly among males (eg. Berry & Harrison, 2008). As such, there has been considerable interest in identifying factors which contribute directly to, or increase the risk of, road crashes. One particular factor which has received attention is the psychological characteristics of the young driver.

The psychological characteristics of the young driver include relatively unstable states such as anxiety and depression (Marengo, Settanni, & Vidotto, 2012), and relatively stable traits such as sensation seeking propensity and impulsivity (Ulleberg, 2001; Marengo et al., 2012). Of relevance to young driver road safety, and other adolescent and young adult health-related behaviours, is the trait of reward sensitivity. The role of rewards in learning and repeating behaviour is well recognised (Beck, 1990). Rewards are motivating, and can be external (such as gaining 'cool' status within the friendship group, eg. Scott-Parker et al.

2009; Weston & Hellier, in press) or internal (such as ‘feeling good’ when traversing a corner at high speed, eg. Scott-Parker et al., 2009; or ‘enjoying the risk’ of drinking and driving, e.g. Greening & Stoppelbein, 2000). In contrast, while punishments can also be motivating, they can also be external (such as a traffic infringement, eg. Scott-Parker & Bates under review; Freeman et al, 2006) or internal (eg. anxiety experienced in response to risky driving behaviour, eg. Scott-Parker in press; or the negative feeling that they are breaching the trust of their passengers, e.g. Fleiter, Lennon & Watson, 2010). Behaviours which are perceived to be punishing are less likely to be repeated, while behaviours which are perceived to be rewarding – of particular interest for this literature review – are more likely to be repeated.

While the level of risk – and arguable the punishments and the rewards – that individuals accept in any given situation differs substantially from individual to individual, the young driver’s sensitivity to reinforcement exerted by rewards and punishments appears to be regulated by the two neurological systems central to reinforcement sensitivity theory (Corr, 2009): the behavioural activation system (BAS) which influences the individual’s sensitivity to rewards; whilst conversely the individual’s response to punishments – effectively the opposite of a reward – appears to be regulated by their behavioural inhibition system (BIS) of motivation. It is suggested that these two systems mediate an individual’s response to any given event in his or her environment (Genovese & Wallace, 2007). That is, differing levels of activity within these two systems are displayed behaviourally as the personality traits of sensitivity to reward and sensitivity to punishment. BIS is responsible for avoidance of an action in response to punishment, frustrative non-reward and novel stimuli. When the BIS is activated inappropriate behaviours are suppressed and response choice becomes more selective (Avila, 2001). In contrast, BAS controls approach behaviour and is activated only by conditioned signals of reward or non-punishment – of particular interest for this literature review. Thus these signals determine approach or active avoidance behaviour

(Avila, 2001). An individual with an overactive BIS is likely to display high sensitivity to punishment, and is thus more prone to response inhibition when faced with punishment cues. In contrast, an individual with an underactive BIS will be less likely to be deterred from an action by a punishment cue. Similarly, individuals with an overactive BAS will display high sensitivity to reward and thus have trouble with inhibitory learning due to this strong motivation towards rewards. In contrast, individuals with an underactive BAS are less likely to be affected by temptation of a reward, with them being primarily concerned with predicting and avoiding the aversive consequences experienced as a result of a particular event (Avila, 2001; Avila & Torrubia, 2004).

The concept of reward sensitivity as a factor implicated in young drivers' behaviour is relatively novel in terms of terminology and formal investigation; however rudimentary versions of the notion date further back in time. For example Hagenzieker (1992) surveyed young male drivers and found differing opinions on the efficacy of incentives versus enforcement for promoting seat belt usage. Similarly in a later meta-analytic study Hagenzieker et al. (1997) evaluated the effect of different incentive programmes, finding that the immediacy of the incentive, and whether the incentive used was based on individual or group behaviour, influenced the magnitude of the reported effect of the programme. These studies illustrate how the use of incentives to encourage safe driving has been investigated by researchers in the past. However it is only relatively recently that reward sensitivity as a factor implicated in the risky driving behaviour of young drivers has started to be investigated in any depth. The purpose of this paper is to review the literature on (a) the relationship between reward sensitivity and risky driving, (b) the relationship between reward sensitivity and risky decision making, and (c) the relationship between reward sensitivity and risky health behaviours per se. In this way promising and heretofore unrealised avenues of

effective intervention in young driver road safety, and adolescent and young adult health risk behaviour, may be identified.

Method

Search terms including ‘reward sensitivity’, ‘sensitivity to reward’, ‘risk’, ‘reward AND behaviour’ and other variations (e.g., ‘behavior’) were used in database searches of PsychINFO and Science Direct with a (paper and/or online) publication date up to and including 15 September 2014. For the purposes of this review, Avila’s (2001) definition of reward sensitivity was used, namely that: reward sensitivity is the behavioural trait of BAS, representing approach behaviour in response to incentives, either in the form of signals of reward or non-punishment. As the study of reward sensitivity in the context of risk is still a relatively new field of study, no particular parameters regarding the types of instruments used to measure the concept of reward sensitivity were set *a priori*. The primary criterion for inclusion was whether the reported methodology included explicit measurement of reward sensitivity in the context of a risky behaviour. To this end, six papers were excluded on the basis that they failed to isolate reward sensitivity as an independent construct (e.g. Machin & Sankey, 2007; Marcil, Bergeron & Audet, 2001; Oehl & Hoger, 2014). In addition, it is noteworthy also that while the influence of reward sensitivity as a potential factor implicated in risk-taking behaviour among adolescents per se is well recognised, thus the literature regarding reward sensitivity and risk is included, the influence of reward sensitivity as a potential factor implicated in the risky behaviour of young drivers specifically is less well researched. Accordingly studies not related to road safety are included to illustrate how generalised sensitivity to reward and risk-taking behaviour may be related.

Results

Based on the aforementioned search parameters, the literature search yielded a return of 31 studies. The review of the literature is organised into three sections which focus on

risky driving behaviour; risky decision-making, and other risky health-related behaviours.

Two types of analyses were most commonly performed by researchers: correlations/ regressions of reward sensitivity with risky behaviour and t-tests/ analyses of variance on mean reward sensitivity differences between high and low risk groups.

Reward sensitivity and risky driving behaviour

Table 1 summarises the literature regarding the relationship between risky driving and reward sensitivity. Eleven papers were identified, and within the broader category of risky driving behaviour, the literature is synthesised within the scope of the following subsections: Reward sensitivity and self-reported driving behaviour; and Reward sensitivity and driving violations. All but one study has participants aged 17-25 years only, with all but two papers with publication dates of 2011 or later. Six of these papers originated from Australia, and a further four papers originated from Europe and the United Kingdom. Self-report surveys featured in nine papers, with one paper operationalising a longitudinal methodology.

[insert Table 1 here]

1. Reward Sensitivity and self-reported driving behaviour

Of 11 papers examining reward sensitivity and risky driving behaviour, 9 papers explored issues concerned with the relationship between reward sensitivity and young drivers' self-reported driving behaviour. Greening and Stoppelbein (2000) explored young drivers' drink driving intentions and their intrinsic/ extrinsic reward motivations using a questionnaire based on the Protection Motivation Theory (PMT). The PMT model was found to predict intentions to drink and drive, with 70% of the variance explained by young drivers perceiving rewards for drinking and driving. Young drivers who perceived rewards for drinking and driving were significantly more likely to report intentions to drink and drive than those who did not perceive drinking and driving to be rewarding. In addition, Kaye, White and Lewis (2014) explored the extent to which BAS and the Fight-Flight-Freeze System (FFFS)

influenced both the processing of gain-framed and loss-framed road safety messages; and the acceptance of the road safety subject message for a group of young drivers (Participants viewed one of four road safety messages and BAS and FFFS traits were assessed using self-report personality and behavioural measures, finding that processing biases towards gain-framed messages appeared to lead reward-sensitive individuals to adopt safer driving behaviours. This is one of very few studies to investigate the potential for using the trait of reward sensitivity in individuals for the purpose of encouraging safe driving.

Castella and Perez (2004) administered the *Sensitivity to Punishment and Sensitivity to Reward Questionnaire* (SPSRQ) (Torrubia et al., 2001) to 792 adults as well as a scale of monotony avoidance and two Likert scales regarding attitudes and behaviour toward traffic violations. Drivers with high punishment sensitivity and low reward sensitivity tended to report driving in compliance with the law; whilst those with low punishment sensitivity and high reward sensitivity reported violating the law more often. Reward sensitivity was a stronger determinant in violating the law than punishment sensitivity was in encouraging compliance, with drivers who perceived less danger in the infringements also showing greater risk. Gender differences were also found: males responded more to reward and females more to punishment; with males reporting a greater number of fines and greater non-compliance. Constantinou et al. (2011) also explored the influence of personality, age and gender on crash-involvement. Consistent with the findings of Castella and Perez (2004), males scored higher on reward sensitivity and lower on punishment sensitivity. Males also reported more crashes and traffic offences than females, particularly deliberate aggressive violations rather than driving errors. Amongst other personality factors, regression analyses were performed on participants' sensitivity to reward and their driving violations. Sensitivity to reward was found to contribute to the variance explained for ordinary violations and structural equation modelling suggested that personality may be an indirect predictor of negative driving

outcomes. High levels of reward sensitivity, impulsivity, thrill seeking and disinhibition (i.e. seeking intense social experiences) was associated with poor driving; and this association decreased with age.

Harbeck and Glendon (2013) explored the effect of reinforcement sensitivity and perceived risk on young drivers' engagement in risky driving. The researchers employed Carver and White's (1994) behavioural inhibition and behavioural activation (BIS/BAS) scales to assess punishment sensitivity and two forms of behavioural approach – reward responsiveness (BAS-RS) and fun seeking (BAS-FS).. Young drivers with higher levels of BAS-fun seeking reported lower perceived risk of the risky driving behaviours, and that risky driving behaviours were less risky as a result of the perceived "fun" that they provided. The opposite was found for BIS: higher BIS scores were associated with higher perceived risk for risky driving behaviours, and participants with higher BIS scores were more concerned with potential negative effect of law enforcement, injury and death so perceived the behaviours as more risky. Interestingly, higher BAS-reward responsiveness was associated with higher perceived risk.

Scott-Parker, Watson, King and Hyde (2012) explored the relationship between psychological distress, reward sensitivity, sensation seeking and risky driving behaviour for a group of young novice drivers. Participants completed several measures, including Kessler et al's (2003) *K10 Psychological Distress Scale*, Scott-Parker et al's (2010) *Behaviour of Young Novice Drivers Scale* (BYNDS); and the SPSRQ. The influence of punishment sensitivity was found to be subsumed within the influence of anxiety and depression. Whilst conceptually reward sensitivity and sensation seeking are similar, and the indices are highly correlated, the constructs were found to exert differential influence upon self-reported risky driving. Anxiety, depression, reward sensitivity and sensation seeking propensity predicted

risky driving, with gender a moderator such that all variables except anxiety predicted risky driving for young males, whilst all four variables predicted risky driving for young females. Extending these findings, Scott-Parker et al (2013a) explored the relationship between psychological distress, reward sensitivity, sensation seeking and risky driving for a second group of young novice drivers, finding that anxiety, reward sensitivity and sensation seeking propensity predicted risky driving. Gender again was a moderator with only reward sensitivity predicting risky driving for young males. Scott-Parker et al.'s (2013b) follow-up study considered the influence of reward sensitivity, among other personality characteristics, on self-reported speeding of young novice drivers. Participants completed two online surveys within a six month interval, completing the K10, the SPSRQ, and the BYNDS (in addition to other measures). Using this longitudinal sample, personal attitudes explained the most variance in speeding, particularly for females. However for males, greater reward sensitivity was predictive of more self-reported speeding, whilst greater risk assessment was predictive of less self-reported speeding. Scott-Parker et al. (2013c) used cluster analysis techniques to identify 'problem young drivers' based on the responses of the participants of (2013a). Three groups of young drivers were identified, with the drivers in the highest risk group exhibiting significantly greater reward sensitivity. These drivers also reported the greatest sensation seeking propensity, depression, and anxiety, and reported the most risky driving (including indicators such as pre-Licence driving, unsupervised Learner driving, car crashes, driving offences, and speeding).

2. Reward sensitivity and driving violations

Of 11 papers examining reward sensitivity and risky driving behaviour, 2 papers explored the relationship between reward sensitivity and young drivers' actual driving violations in simulator studies. Jongen, Brijs, Komlos, Brijs and Wets (2011) used the dual systems model of adolescent risk taking to investigate the influence of cognitive control and rewards on a

measure of young drivers' actual risky driving. Drivers aged 17-24 years completed the stop signal paradigm (Logan & Cowan, 1984) as a measure of inhibitory control, within a driving simulator context, and while inhibitory control was found to be still developing, a rewarding context in particular predicted risky driving: On trips in which a reward of monetary reinforcement was offered, speeding and red light running occurred more often than on non-reward trips. Lansdown and Saunders (2012) used the market type, payment and effort model from Heyman and Ariely's (2004) paper to investigate the influence of reward on performance of a driving task. In this study, males aged 18-38 years were randomly allocated to a no-payment, low-payment or medium-payment condition in a driving simulator. Participants undertook easy and difficult divided attention driving tasks, in which reaction times were measured. When drivers were not rewarded, they displayed reduced vehicle control and more time pressure. In general, driving performance improved with the level of reward provided, with performance was worst when no reward was offered.

Reward Sensitivity and Risky Decision Making

Table 2 summarises the literature on the relationship between risky decision making and reward sensitivity. Five papers were identified (one paper only was published prior to 2011), and the methodology and main findings will be discussed. One paper has participants aged 18-72 years, one paper uses young rats, whilst the participants are aged 18-28 years in one paper and 18-25 years in the remaining two papers. One paper originated from Australia, and a further three papers originated from Europe and the United Kingdom. Computer-based testing featured in four of the five papers which all utilised a cross-sectional methodology

[insert Table 2 here]

Balodis, Thomas and Moore (2014) used RST (Gray & McNaughton, 2000) and the cognitive behavioural pathways model of pathological gambling (Blaszczynski & Nower, 2002) to explore the relationship between gambling choice and frequency with sensitivity to

punishment and reward. Participants were all current gamblers (defined as gambling twice or more per year); and were predominantly males aged 18-72 years. Self-reported horse race gambling frequency was independently predicted by male gender and reward sensitivity, while electronic gaming machine gambling was predicted by escapist motivation and punishment sensitivity. Horse race gamblers were typically young males, high on sensation seeking and BAS driven; behaviour driven by a tendency to seek reinforcement and their motivation for gambling related to being drawn to the exciting possibility of a win. Penolazzi, Gremigni and Russo (2012) explored how the personality traits of reward sensitivity and punishment sensitivity affect risky choices via self-report measures, including the BIS/BAS scales of punishment sensitivity and reward sensitivity, as well as the Columbia Card Task (CCT, Figner et al., 2009). Participants who scored high on the reward responsiveness trait were more likely to engage in more risky decision making when there were high gains to be won; even underestimating the potential effects of co-occurring high losses.

Buelow and Suhr (2013) examined the relationship between various personality characteristics, state mood and card deck selections using Carver and White's (1994) BIS/BAS scale to assess punishment sensitivity and reward sensitivity, along with impulsivity and positive and negative affect. In the IGT, certain decks are more advantageous than others, and participants must make decisions based on the level of risk they are willing to accept, in order to win more money. The researchers found that individuals scoring high on BAS-drive chose more cards from risky Deck B, and made fewer safe Deck D selections; indicating higher levels of BAS (reward sensitivity) are associated with riskier decisions on the IGT. Weston and Hellier (2014) also operationalised the IGT, investigating the relationship between reward sensitivity and punishment sensitivity and risk taking in conjunction with the SPSRQ. Males with high reward sensitivity (BAS) were found to choose more cards from 'risky' Deck B than did females or low BAS males. Punishment sensitivity

(BIS) was not related to card selections, suggesting that for young males, riskier decisions are associated with reward sensitivity.

Rivalan, Ahmed and Dells-Hagedorn (2009) explored the cognitive processes underlying decision making in rats by developing a rat version of the IGT that assessed risky decision making. The researchers argued this was necessary as there is a lack of suitable animal models that assess complex decision making; particularly in situations where immediate gratification is favoured over long-term gain. Whilst the majority of rats worked out the favourable options rapidly, some systematically chose disadvantageously, regardless of task complexity, suggesting that poor decision making did not occur as a result of failing to learn the information needed to make an advantageous decision, rather poor decision making occurred as a result of a hypersensitivity to reward and higher risk taking.

Reward Sensitivity and Risky Health Behaviour

Table 3 summarises the literature regarding the relationship between various other risky health-related behaviours and reward sensitivity. Fifteen papers were identified, and within the broader category of risky health behaviour, the literature is synthesised according to: Reward sensitivity and substance use; Reward sensitivity and dysfunctional eating; Interaction between reward sensitivity, risky health behaviour and other factors. Ten of the 15 papers had a publication date of 2011 or later. The age range of the participants varies widely, from 10-16 years to an average age of 56 years. Six of these papers originated from Australia, three papers originated from Europe and the United Kingdom, and a further six papers originated from the United States. Self-report surveys featured in six papers, five papers report fMRI findings, and two papers operationalised a longitudinal methodology

[insert Table 3 here]

1. Reward sensitivity and substance misuse

Of 15 papers examining reward sensitivity and risky health behaviour, 5 papers explored the relationship between reward sensitivity and substance misuse. For example, Balconi, Finocchiaro and Canavesio (2014) investigated the impact of BAS and cortical frontal asymmetry (left-lateralisation effect) on Substance Use Disorder (SUD) in decisional processes using the IGT.. The SUD group were more likely to opt in favour of immediate reward (loss strategy) than the long-term option (win strategy) compared to the control group. The SUD group had higher reward-subscale scores and showed an increase in left-hemisphere activation in response to losing (with immediate reward) choices in comparison to the control group, suggesting that higher BAS traits may be related to the imbalanced left hemispheric effect.

Simons and Arens (2007) explored the relationship between reward and punishment sensitivity and marijuana use in a large sample of 18-25 year-olds. Participants completed the SPSRQ and the *Marijuana Effect Expectancies Questionnaire* (Aarons et al., 2001), regular marijuana users reporting lower punishment sensitivity and greater reward sensitivity than nonusers. Reward sensitivity was associated with more positive marijuana expectancies and conversely punishment sensitivity was associated with more negative marijuana expectancies, reward sensitivity attenuating the association between punishment sensitivity and the probability of marijuana use. Smerdon and Francis (2011) also used the SPSRQ to examine the relationship between reward sensitivity and ecstasy use in young adults. The frequency of ecstasy use was related to reward sensitivity and positive outcome expectancies such that those with the highest reward sensitivity scores were more likely to report higher ecstasy use. Regression analyses revealed however that sensitivity to reward was not a significant predictor of ecstasy use.

White, Cunningham, Pearce and Newnam (2014) investigated the influence of reward sensitivity on attentional bias towards alcohol-related cues. Participants were 18-25 year old

binge drinkers who completed the BAS scale of reward sensitivity, rFFF measure of punishment sensitivity and the Alcohol Use Disorders Identification Test (AUDIT, Saunders et al., 1993).. Stronger reward sensitivity and weaker punishment sensitivity predicted stronger attentional bias towards alcohol cues, and attentional bias was associated with more self-reported drinking. Morgan, Bowen, Moore and van Goozen (2014) investigated the relationship between reward and punishment sensitivity and antisocial behaviour in male adolescents. Higher levels of BAS (reward sensitivity) and lower levels of BIS (punishment sensitivity) were found in the offenders group, compared to non-offenders. Traits associated with reward sensitivity (BAS Drive and Fun seeking) predicted psychopathic traits, conduct problems and alcohol use. Response to reward (BAS reward responsiveness) was negatively associated with psychopathy and conduct problems which was also the only BAS subscale to be positively associated with BIS. The researchers posited that low reactivity to both rewarding and punishing stimuli is associated with antisocial behaviour, and this is consistent with under-arousal often shown by antisocial individuals.

2. Reward sensitivity and dysfunctional eating

Of the 15 papers examining reward sensitivity and risky health behaviour, 3 papers explored the relationship between reward sensitivity and dysfunctional eating behaviour. Fay, White, Finlayson and King (2014) investigated the relationship between reward sensitivity and overconsumption of high-calorie foods. Measures of food, sensitivity traits (assessed using the BIS/BAS scales) and behavioural rewards (CARROT, Powell, Al-Adawi, Morgan & Greenwood, 1996) were administered. Snack food intake was also measured, both with and without a 'food cue', in which participants were presented with images of high calorie food and instructed to focus on it, think about what it would be like to eat it, but not taste it. Sensitivity to food reward, but not generalised reward sensitivity, was positively associated with snack food intake, and this relationship was not affected by the presence of a food cue.

The relationship between reward and punishment sensitivity and dysfunctional eating has also been explored by Loxton and Dawe (2006) in a study operationalising the SPSRQ, the Drive for Thinness (DT) and Bulimia scales of the Eating Disorders Inventory 2 (EDI) (Garner, 1991) and AUDIT. Reward sensitivity was directly associated with both dysfunctional eating and drinking, while punishment sensitivity was associated with dysfunctional eating but not hazardous drinking; suggesting that reward and punishment sensitivity are key traits to examine when investigating vulnerability to risky behaviour. A follow-up study was conducted by Loxton and Dawe (2007) to explore whether the use of behavioural measures of punishment and reward sensitivity would yield similar results.. Although self-reported reward sensitivity with dysfunctional eating and both reward sensitivity and impulsivity were associated with hazardous drinking, when performance on the CARROT task of reward sensitivity was assessed, it was found not to correlate with self-reported reward sensitivity/impulsivity or disordered behaviour.

3. Interaction between reward sensitivity, risky health behaviour, and other factors

Of the 15 papers examining reward sensitivity and risky health behaviour, 7 papers explored how reward sensitivity and risky health behaviour may be related to other factors such as personality characteristics or social contexts. For example, Steinberg (2010) implemented a dual systems model of adolescent risk-taking to explore the age differences in reward-seeking and impulsivity. A large sample of participants completed the *Barratt Impulsiveness Scale, Version 11* (Patton, Stanford & Barratt, 1995) and the reward-seeking subset of the SSS (Zuckerman, Eysenck & Eysenck, 1978). Age differences in reward-seeking followed a curvilinear pattern, increasing between preadolescence and mid-adolescence, and declining thereafter. In contrast, the age differences in impulsivity followed a linear pattern, declining steadily from age 10 years onwards. It appears that heightened vulnerability to risk-taking in middle adolescence may be due to the combination of relatively

higher inclinations to seek rewards and still-maturing capacities for self-control, which has considerable implications for effective interventions for adolescents, including road safety interventions.

Braams, Peters, Peper, Guroglu and Crone (2014) examined adolescents' reward sensitivity in different social contexts. Participants completed a monetary reward-processing task in which they could win or lose money for themselves, their best friend, and a disliked peer. The researchers found that mid- to late-adolescence was associated with a specific peak in neural activation in the ventral striatum when winning for self, while winning for a disliked peer resulted in a specific peak in the medial prefrontal cortex for this age group. Hypersensitivity to reward in adolescence was also found to be dependent on social context, suggesting that increased risk-taking and sensation seeking observed in adolescence may be strongly related to the social context in which they occur, and are not purely related to hyperactivity of the ventral striatum. DeYoung, Hawes, Cimai and Rustichini (2014) explored the relationship between extraversion and neural reward sensitivity, using a large fMRI sample of participants. Brain activity was measured while participants undertook two independent tasks: a reinforcement activity (guessing whether a computer-generated number would be high or low) and a decision making task assessing delay discounting (choosing between smaller, sooner rewards, and larger, later rewards). Extraversion (and not other 'Big Five' personality traits such as neuroticism and agreeableness) was associated with neural sensitivity to monetary reward, further supporting the theory that extraversion reflects reward sensitivity.

O'Brien, Albert, Chein and Steinberg (2011) investigated the effect of peer presence on adolescent risk-taking behaviour. A sample of late adolescents completed a delay discounting task in which they had to choose between a series of immediate rewards and delayed rewards of given amounts. Participants were randomly assigned to complete the task

alone or with two same-age same-sex peers observing. In the presence of peers, participants tended to demonstrate a greater preference for immediate rewards than when on their own, suggesting that the heightened risk taking adolescents engage in when they are with their friends may be due in part to the effect that peer presence has on their reward sensitivity.

Op de Macks, Moor, Overgaauw, Guroglu, Dahl and Crone (2011) examined the relationship between pubertal maturation, gonadal hormones, reward processing and risky behaviour in a healthy sample of 10-16 year-olds at different stages of puberty. Higher testosterone levels were related to an enhanced striatum response to reward, suggesting that changes in reward processing – which affect risk taking behaviour – are associated with changes in limbic brain regions that are specifically influenced by gonadal hormones.

Telzer, Fuligni, Lieberman and Galvan (2013) took an alternative approach: exploring the effect of heightened reward sensitivity on adolescents' longitudinal display of prosocial activities. Students aged 15-18 years (completed the *Rule-Breaking* subscale of the *Youth Self-Report form of the Child Behaviour Checklist* (Achenbach, 1991) and the *Cognitive Appraisal of Risky Events* (CARE) Questionnaire (Fromme et al, 1997) at two time points separated by a one-year interval. Participants also took part in a family assistance task whilst in the fMRI scanner; earning money for themselves and their families by responding to a series of financial offers that differed in the associated level of costly and non-costly rewards. Participants with heightened ventral striatum activation to prosocial stimuli were found to exhibit longitudinal declines in risk taking, suggesting the same brain region that predicts vulnerability for adolescent risk taking may also be protective against risk taking. Providing assistance to one's family was particularly predictive of reduced risk taking in high reward sensitive individuals. Voigt, Dillard, Braddock, Anderson, Sopory, and Stephenson (2009) explored the relationship between BIS/BAS and engagement in various risky health behaviours. A large sample of participants aged 17-69 years completed Carver and White's

(1994) BIS/BAS scales and the *2007 State and Local Youth Risk Behaviour Survey*. Contrary to expectation, reward-responsiveness served as a protective force against engagement in risky health behaviours (sex, alcohol, drug and tobacco use, personal safety, inactivity, poor diet). By contrast the *Fun Seeking* subscale of BAS was found to be strongly and positively associated with all but two of the risky behaviours (inactivity, diet), suggesting that considerations of reward sensitivity should also more fully consider which aspects of reward sensitivity not only are conceptualised but are also influential.

Discussion

Synthesis of the literature

The literature regarding the relationship between reward sensitivity and risky driving behaviour was reviewed. A synthesis of the findings reported in the 11 papers reveals that greater reward sensitivity is associated with decreased compliance with road rules and poorer driving more generally (R^2 ranging from 27% to 70%). Males consistently exhibited greater reward sensitivity, in addition to greater noncompliance, crash-involvement, and offences-detected. Reward sensitivity was also found to be highest in the young drivers with the most problematic driving styles ('the problem young driver', Scott-Parker et al. 2013c). Some of the literature examined the relationship between perceived and anticipated rewards, and actual and anticipated risky driving behaviour. Perhaps unsurprisingly, greater rewards such as getting a thrill from driving after drinking, or perceiving encouragement from friends for drink driving, were associated with greater intentions to drink drive (Greening & Stoppelbein, 2000). Consistent with the orientation towards rewards, gain-framed messages increased the acceptance of safety messages for young drivers with greater reward sensitivity (Kaye et al., 2014).

Regarding monetary rewards in simulator-based studies, the relationship between rewards and performance is less clear: in one study a monetary incentive resulted in more

risky driving (Jongen et al., 2011) whilst in a second study a lack of reward resulted in the worst driving performance overall (Lansdown & Saunders, 2012). Furthermore, whilst conceptually the trait reward sensitivity is similar to sensation seeking propensity, and the two constructs are highly correlated (correlations ranging from .42 to .52) research consistently demonstrated that the two traits exert separate influences upon the risky driving behaviour of young drivers (Scott-Parker et al., 2012, 2013a, 2013c), including speeding (Scott-Parker et al., 2013b).

Regarding the BAS which regulates reward sensitivity, some studies examined BAS-reward responsiveness, BAS-drive and BAS-fun seeking as separate constructs of influence. To demonstrate, greater reward sensitivity was found to be related to greater perceived risk for risky driving behaviour; however it appears that this influence is via the BAS-fun seeking construct (that is, there is a trade-off between the risk associated with the behaviour for the anticipated fun that will be experienced as a result of performing the behaviour) (Harbeck & Glendon, 2013).

The literature regarding the relationship between reward sensitivity and risky decision making was also reviewed, with greater reward sensitivity consistently related to more risky decisions in activities like horse race gambling (Balodis et al., 2014) and computer-based card selections (Buelow & Suhr, 2013; Weston & Hellier, 2013). In one study up to 40.8% of the variance in risky decision making was found to be attributed to male gender and reward sensitivity (Balodis et al., 2014). Individuals with greater reward sensitivity also underestimated the impact of losses. Taken together, these findings suggest that high-reward sensitivity individuals are driven by the desire for reinforcement. Whilst traditionally an animal study would be excluded from a literature review regarding human behaviour, the findings of the Rivalan et al. (2009) study merit further consideration and therefore inclusion within the summary: a sub-sample of rats consistently made poor, hasty decisions in an

attempt to gain a reward – despite learning that good decisions would mean a reward in due course – which suggests that the rats were hypersensitive to rewards and were engaging in high risk behaviours. Extrapolating beyond rodent traits and behaviours, these findings suggest that the trait of reward sensitivity may be robust in mammals more generally.

Finally, the literature regarding the relationship between reward sensitivity and risky health behaviours more generally was reviewed. Greater reward sensitivity was found to be associated with a range of risky behaviours including substance use (Balconi et al., 2014) such as marijuana (Simons & Arens, 2007) and ecstasy (Smerdon & Francis, 2011) (correlations ranging from $-.18$ to $.13$), dysfunctional eating (Fay et al., 2014), and dysfunctional drinking (Loxton & Dawe, 2006, 2007) (correlations ranging from $.21$ to $.28$).

An age-related trend was apparent in research which included older participants, such that reward sensitivity peaks in mid-adolescence before declining in adulthood (Steinberg, 2010). This is consistent with the findings of Scott-Parker et al. (2012) in which a statistically significant reduction in reward sensitivity was found during the six-month follow up period. From a personality perspective, extraversion was found to reflect reward sensitivity (De Young et al., 2014). Furthermore, offenders with an antisocial personality were found to have greater reward sensitivity, with their psychopathic traits predicted by BAS-drive and BAS fun seeking. BAS-reward responsiveness, in contrast, was negatively associated with psychopathy and conduct problems, further highlighting the complexity of the influence of the BAS construct, and reward sensitivity in particular (Morgan et al., 2014).

fMRI studies have revealed that young adults exhibited greater reward sensitivity when they were in the presence of their peers, suggesting a heightened sensitivity to potential rewards in this social context (Chein et al., 2011). fMRI studies have also identified differences in cognitive processing for individuals high on reward sensitivity compared to individuals low on reward sensitivity, including greater-left hemisphere activation for losses

during IGT (Balconi et al., 2014), and a lack of neural response in the absence of a reward (Braams et al., 2014). The lack of a neural response regarding losses in individuals with greater reward sensitivity suggests that such individuals are oriented to rewards with fewer attentional resources allocated to negative outcomes. These findings are consistent with a greater attentional bias towards alcohol cues in persons who engage in binge drinking (White et al., 2014), with BAS-reward responsiveness decreasing the likelihood of risky behaviour whilst BAS fun-seeking increases the likelihood of risky behaviour. This is consistent with the findings of Voigt et al., (2009) who found great reward responsiveness was associated with decreased engagement in risky behaviours like drinking and smoking.

Implications for young driver road safety and other health risk behaviour

The research findings suggest that reward sensitivity is a relatively robust trait amongst adolescents and young adults, and this has considerable implications for effectively intervening to maximise their road safety and to minimise the risks associated with poor decision making and engagement in other risky health-related behaviours. Reward sensitivity seems to peak in adolescence right at the time when the adolescent is first able to drive independently. Coupled with the finding that peer presence appeared to attune the adolescent to rewards, it appears that a perfect storm is more likely for young drivers more generally, and potentially for males who tend to exhibit greater reward sensitivity in general. The finding that gain-framed messages increased the acceptance of young drivers with greater reward sensitivity suggests that interventions – including the traditional ‘3 Es’ of education, enforcement, and engineering, augmented by the fourth ‘E’ of engagement – should be oriented to emphasise the benefits of safe driving and other health risk behaviours and safe decision-making, rather than the traditional approach of emphasising the negative consequences of such behaviours and/or decisions. The finding that providing assistance to family members decreases risk for the adolescent merits further consideration also: A novel

intervention approach may be to emphasise the rewarding effects of providing prosocial assistance to the family. Previous findings have shown that adolescents who have prosocial peers and who are more prosocial and altruistic themselves engage in much less risky behaviours (Oman et al., 2004; Machin & Sankey, 2008). By providing adolescents with the means of attaining an alternative source of reward they may find potentially life-threatening risk taking contexts to be less rewarding as a result.

Future research

Methodological considerations point to several research directions (Scott-Parker & Senserrick, 2013, 2017). Seventy-five percent of the papers reviewed had a publication date of 2011 or later, indicating the recent research interest in the trait construct of reward sensitivity and its relationship to risky behaviours and risky decision-making. The majority of these papers emerged from research undertaken in Australia (42%) and Europe and the United Kingdom (32%). The generalisability of these papers to young driver road safety and interventions in all motorised jurisdictions is thus questionable (Scott-Parker & Senserrick, 2013, 2017). As such, future research could be undertaken in other jurisdictions, with a particular focus on non-western countries in particular. Fifty-eight percent of the papers included only participants aged 25 years and less. Whilst research across the lifespan is important for understanding reward sensitivity per se, given that less than 10% of the studies operationalised a longitudinal methodology, such wide sampling may have impacted upon the interpretability and implications of the research findings. In addition much of the research to date has relied on self-report and simulation measures, limiting the ecological validity of the evidence base. Future research in this domain would benefit from using real-world driving methodologies in order to robustly demonstrate the nature of the relationship between reward sensitivity and risky driving behaviour among young drivers.

The synthesised findings also point to several research directions. Reward sensitivity, and BAS specifically, appears to be comprised of several dimensions. To demonstrate, reward responsiveness seems to decrease risky driving and other health-related behaviours, while fun seeking appears to increase risk. Future research should attempt to elucidate the path models of influence, and in particular any mediation or moderation effects, of these dimensions, in addition to the BAS-drive dimension. Further research is also required to understand the ways in which reward sensitivity interacts with other personal and attitudinal factors to influence young drivers' behaviour; and to investigate whether particular driving contexts elicit reward-seeking behaviour among this cohort to a greater degree than others. The influence of peers on attention to and motivation for rewards (particularly for high reward sensitivity individuals), and males generally, merits further investigation, particularly as peers seem to act as 'triggers' for risky behaviour in many instances. In addition, the finding that prosocial behaviour can to some extent mediate the negative influence of reward sensitivity merits further exploration and modelling. Individual differences in reward sensitivity prevail, with recent research highlighting the important role that emotions play during adolescence (Scott-Parker, under review); future research should examine any reward and reward sensitivity influence specific to the breadth of psychosocial-cognitive-biological maturation characteristic of adolescence. Finally, there is increasing interest regarding the potential road safety benefits arising from the application of incentives (i.e., rewards) to reduce unsafe driving behaviours, (e.g., to reduce speeding behaviour by young drivers, Bolderdijk, Knockaert, Steg, & Verhoef, 2011; to encourage seat belt use, Hagenzieker, Bijleveld, & Davidse, 1997). Arguably such interventions are applications of reinforcement sensitivity theory (Corr, 2009); these two bodies of work (that reviewed here, and that exploring the influence of incentives) are inextricably intertwined both theoretically and in an applied context, albeit that it appears that largely these connections have been intentionally or

inadvertently omitted and/or overlooked within the development, application, and evaluation of these studies, and within the reporting that has occurred through the peer-reviewed literature published during the search period. Future reward-based interventions would benefit from an application of psychosocial theories such as reinforcement sensitivity theory,

Conclusions

A literature review and synthesis of the literature regarding reward sensitivity has summarised the research pertaining to the relationships between reward sensitivity and risky driving, risky decision-making, and engagement in other risky health-related behaviours such as using marijuana and unhealthy eating. Of the 31 papers identified, 75% were published in 2011 or later, demonstrating the recent interest in this psychological trait in the domain of risky decisions and health-related behaviours. Males were found to exhibit greater reward sensitivity, and individuals with greater reward sensitivity generally were found to engage in risky driving behaviours, risky decision making, and other risky health-related behaviours in greater rates than individuals with lower reward sensitivity. In addition, the greater reward sensitivity of adolescents, coupled with an attentional bias towards being rewarded in the presence of peers, appears to be particularly problematic for young driver road safety, particularly at a time when the young driver is first able to drive unsupervised. Consideration of the influence of reward sensitivity in young driver road safety, and other adolescent/young adult health-related safety, appears to be a promising avenue of intervention, with gain-framed messages more likely to be accepted by young drivers with greater reward sensitivity. Future research should also attempt to delineate the differential impact of the reward responsiveness and the fun seeking elements of reward sensitivity.

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Table 1. The relationship between reward sensitivity and risky driving behaviour.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
<i>Reward sensitivity and self-reported driving behaviour</i>					
Greening & Stoppelbein, (2000) Alabama, USA	Drink driving intentions	304 drivers (both genders), aged 17-20 years old, attending college	Likert scales of intrinsic and extrinsic reward motivation and intentions to drink and drive	Regression analyses	The Protection Motivation Theory model predicted intentions to drink and drive. Young drivers who perceived rewards for drinking and driving were most likely to report intentions to drink and drive.
Kaye, White & Lewis (2014) Queensland, Australia	Extent to which BAS and FFFS influence processing of gain-framed and loss-framed road safety messages and subsequent message acceptance.	80 drivers (both genders) aged 17-25 years old.	BAS and FFFS assessed using RST-PQ, CARROT and Q-Task	Correlations	Processing biases towards gain-framed messages may lead reward sensitive individuals to adopt safer driving behaviours.
Castella & Perez (2004) Barcelona, Spain	Relationship between sensitivity to punishment and sensitivity to reward and road traffic violations	792 drivers (403 female), secondary school and university students or in paid employment	SPSRQ, Likert scales of traffic violations and attitudes	Correlations	Drivers with low sensitivity to punishment and high sensitivity to reward broke the law most often. Sensitivity to reward was a stronger determinant in violating the law than sensitivity to punishment was in discouraging drivers. Men responded more to reward and women more to punishment.
Constantinou, Panayiotou, Konstantinou, Loutsiou-Ladd & Kapardis (2011) Cyprus	Influence of personality, age and gender as indirect predictors of accident involvement	352 drivers (109 female), aged 18-25 years old	SPSRQ, SSS-V and DBQ	Correlations and regression analyses	High levels of reward sensitivity, impulsivity, thrill seeking and disinhibition (i.e. seeking intense social experiences) were associated with poor driving.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
Harbeck & Glendon, (2013) Queensland, Australia	Effect of reinforcement sensitivity (BIS/BAS scores) and perceived risk on young drivers' engagement in risky driving	165 drivers (101 female) aged 17-25 years old, attending college	Carver & White's (1994) BIS/ BAS scales, 10-item scale of risk perceptions of risky driving behaviours	Regression analyses	Drivers with higher levels of BAS-fun seeking perceived the risky driving behaviours as less risky as a result of the perceived "fun" that they provided. Higher BIS scores were associated with higher perceived risk.
Scott-Parker, Watson, King & Hyde (2012) Queensland, Australia	Relationship between psychological distress, reward sensitivity, sensation seeking and risky driving behaviour of young novices	761 drivers (523 female) aged 17-24 years old	SPSRQ, K10 Psychological Distress Scale, BYNDS.	Regression analyses	Reward sensitivity and sensation seeking propensity exert differential influence, notwithstanding high correlation. Anxiety, depression, reward sensitivity and sensation seeking propensity predicted risky driving. Gender was a moderator with anxiety not a significant predictor of risky driving for males.
Scott-Parker, Watson, King & Hyde (2013a) Queensland, Australia	Relationship between psychological distress, reward sensitivity, sensation seeking and risky driving behaviour of young novices	390 drivers (277 female) aged 17-25 years old	K10, SPSRQ and BYNDS	Regression analyses	Anxiety, reward sensitivity and sensation seeking propensity predicted risky driving. Gender was a moderator with only reward sensitivity predicting risky driving for males.
Scott-Parker, Hyde, Watson & King (2013b) Queensland, Australia	Influence of personality characteristics including reward sensitivity on self-reported speeding behaviour of young novice drivers	378 drivers with a provisional license (265 female) aged 17-25 years old	K10, SPSRQ and BYNDS	Regression analyses	A measurement model for Akers' SLT was developed in a longitudinal sample of young novice drivers. Personal attitudes explained the most variance in speeding, particularly for females. For males, greater reward sensitivity was predictive of more self-reported speeding, whilst greater risk assessment was predictive of less self-reported speeding.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
Scott-Parker, Hyde, Watson & King (2013c) Queensland Australia	Identification of high risk young drivers through demographic, psychological, and behavioural measures	378 drivers with a provisional license (265 female) aged 17-25 years old	K10, SPSRQ and BYNDS	Cluster analysis	Cluster analysis revealed three groups of young drivers. High risk young drivers (13% of sample) exhibited the greatest reward sensitivity, sensation seeking propensity, depression, and anxiety, and reported the most risky driving behaviours (pre- Licence driving, unsupervised Learner driving, car crashes, driving offences, and speeding)
<i>Reward sensitivity and driving violations</i>					
Jongen, Brijs, Komlos, Brijs & Wets (2011) Diepenbeek, Belgium	Influence of cognitive control and rewards on actual risky driving	53 drivers (17 female) aged 17-24 years old.	Stop-signal paradigm (Logan & Cowen, 1984), measures of lateral position, speeding, red light running in driving simulator	MANOVAs and ANOVAs to compare age, reward and inhibitory control.	A rewarding context predicted risky driving. Speeding and red light running occurred more often in the trip with than without the reward of monetary reinforcement.
Lansdown & Saunders (2012) Edinburgh, UK	Influence of reward on performance on a driving task	36 drivers (all male) aged 18-38 years old, attending college.	Monetary rewards differed, reaction times in the driving simulator measured	Correlations and post-hoc tests to assess effect of reward magnitude	When drivers were not rewarded they displayed reduced vehicle control and more time pressure. Performance improved with the level of reward provided. Performance was worst when no reward was offered.

Table 2. The relationship between reward sensitivity and risky decision making.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
Balodis, Thomas & Moore (2014) Swinburne, Australia	Explore relationship between gambling choice (horse race/ EGM- emotionally vulnerable gambler), gambling frequency, personality factors	118 (41 female) aged 18-72 years, current gamblers	SPSRQ and likert scales of gambling frequency	Regression analyses	Horse race gambling frequency was independently predicted by male gender and sensitivity to reward. EGM gambling was predicted by escapist motivation and sensitivity to punishment. Horse race gamblers were typically young males, high on sensation seeking and BAS driven. EGM gamblers were older females, high on BIS and low on sensation seeking and BAS.
Buelow & Suhr (2013) Ohio, USA	Relationship between personality characteristics and state mood on deck selections on Iowa Gambling Task (IGT)	91 (53 female) aged 18-28 years old, attending college	BIS/ BAS scales and Bechara et al's (1994) Iowa Gambling Task (IGT)	Correlations	Greater Deck B selections and fewer Deck D selections were seen among individuals high in sensation seeking and impulsivity. Higher levels of BAS-drive were associated with greater Deck B but fewer Deck D selections indicating higher levels of BAS were associated with riskier decisions on the IGT. BIS was not associated with any deck selections.
Penolazzi, Gemigni & Russo (2012) Bologna, Italy	Exploring the personality traits (e.g. sensitivity to reward and punishment, and sensation seeking) that affect risky choices	132 (73 female), average age 26 years, attending college or working	BIS/BAS, Columbia Card Task (Figner et al, 2009)	ANOVAs	High scorers on reward responsiveness trait were sensitive to variations in gains and losses in the emotional version of the task. High reward-responsive participants could be selectively pushed by high gains to underestimate the potential effects of co-occurring high losses, especially when affective system was involved.
Rivalan, Ahmed, Dellu-Hagedorn (2009) Bordeaux Cedax, France	Understanding the cognitive processes underlying decision making in rats	158 (all male) Wistar Han rats, aged 12-13weeks old.	Rat version of the IGT	ANOVAs	Majority of rats evaluated and deduced favourable options rapidly. Some systematically chose disadvantageously. Poor decision making didn't result from failure to require relevant information; but from hypersensitivity to reward and higher risk taking.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
Weston & Hellier (2013) Plymouth, UK	Relationship between reward and punishment sensitivity and risk taking on Iowa Gambling Task (IGT)	120 (71 female) aged 18-25 years, most attending college	SPSRQ and IGT	ANOVAs	Males with high reward sensitivity (BAS) chose more cards from 'risky' Deck B than did females or low BAS males. Punishment sensitivity (BIS) was not related to card selections. Suggests that for young males, riskier decisions on the IGT are associated with reward sensitivity

Table 3. The relationship between reward sensitivity and other health risk behaviours.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
<i>Reward sensitivity and substance misuse</i>					
Balconi, Finocchiaro & Canavesio (2014) Milan, Italy	Impact of cortical frontal asymmetry (left-lateralization effect) and BAS on Substance Use Disorder (SUD) in decisional processes using the Iowa Gambling Task (IGT)	SUD group: 40, Control group: 42. Average age 56 years, inpatients of drug dependence department (or controls).	BIS/ BAS scales and IGT BIS/ BAS scales and IGT	EEG recordings and ANOVAs	SUD group were more likely to favour immediate reward (loss strategy) more than the long-term option (win strategy) compared to control group. Higher reward-subscale scores observed in SUD, and SUD showed increase in left-hemisphere activation in response to losing (with immediate reward) choices in comparison to control group.
Simons & Arens (2007) South Dakota, USA	Relationship between reward and punishment sensitivity and marijuana use	809 (68% female, 227 marijuana users) aged 18 - 25 years old, attending college	SPSRQ and Marijuana Expectancies Questionnaire (Aarons et al, 2001)	Correlations	Marijuana users reported lower punishment sensitivity and greater reward sensitivity than nonusers. Sensitivity to Reward attenuated the association between sensitivity to punishment and the probability of marijuana use.
Smerdon & Francis (2011) Bundoora, Australia	Relationship between reward sensitivity and ecstasy use in young adults	125 (65 female) aged 18-35 years, students or in employment	SPSRQ and Ecstasy Expectancies Questionnaire (DePino, 2009)	Correlations and regression analyses	Frequency of ecstasy use was related to reward sensitivity and positive outcome expectancies. Those with highest sensitivity to reward scores were more likely to report higher ecstasy use.
White, Cunningham, Pearce & Newnam (2014) Queensland, Australia	The influence of reward sensitivity on attentional bias towards alcohol-related cues.	80 (58% female) aged 17-25 years old, binge drinkers	BAS, rFFF and AUDIT	Correlations and regression analyses	Stronger reward sensitivity and weaker punishment sensitivity predicted stronger attentional bias towards alcohol cues. Attentional bias was also associated with self-reported drinking levels.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
Morgan, Bowen, Moore & van Goozen (2014) Cardiff, UK	Relationship between reward and punishment sensitivity and antisocial behaviour in male adolescents	135 (all males. 85 young offenders, 50 in control group) aged 12-18 years from school or Youth Offending Service	BIS/BAS scales, Youth Self Report (Achenbach & Rescorla, 2001) and the FAST (Hodgson et al, 2002)	Correlations	Heightened BAS (reward sensitivity) and lowered BIS (punishment sensitivity) in the offenders compared to non-offenders. Traits associated with reward sensitivity (BAS Drive and Fun seeking) predicted psychopathic traits, conduct problems and alcohol use. Response to reward (BAS reward responsiveness) was negatively associated with psychopathy and conduct problems.
<i>Reward sensitivity and dysfunctional eating</i>					
Fay, White, Finlayson & King (2014) Queensland, Australia	Relationship between sensitivity to reward and overconsumption of high- calorie foods	50 (56% female), mean age 34.5 years	BIS/BAS scales, CARROT and snack food intake measured	Correlations	Sensitivity to food reward, but not generalised reward, was associated with snack food intake. This relationship was not affected by food cue.
Loxton & Dawe (2006) Brisbane, Australia	Relationship between reward and punishment sensitivity and dysfunctional eating and hazardous drinking	443 (all female) aged 17 - 53 years (85% 30 years and under), attending college	SPSRQ, DT, EDI (Garner, 1991) and the Alcohol Use Disorders Identification Test (AUDIT, Saunders et al, 1993)	Correlations	Reward sensitivity was directly associated with both dysfunctional eating and drinking. Punishment sensitivity was associated with dysfunctional eating but not hazardous drinking. It was suggested that reward and punishment sensitivity are key traits to examine when investigating vulnerability to risky behaviour.
Loxton & Dawe (2007)	The effect of reward and punishment sensitivity on behavioural measures of hazardous drinking and dysfunctional eating	131 (all female) mean age 22.9 years old	CARROT and Q-Task	Correlations	Reward sensitivity was associated with dysfunctional eating. Both reward sensitivity and impulsivity were associated with hazardous drinking. Performance on the CARROT task of reward sensitivity was not associated with self-reported reward sensitivity/impulsivity or disordered behaviour.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
<i>Interaction between reward sensitivity, risky health behaviour, and other factors</i>					
Steinberg (2010) Philadelphia, USA	Age differences in reward-seeking and impulsivity.	935 (both genders) aged 10 - 30 years	BIS, Version 11 (Patton et al, 1995), reward-seeking subset of SSS	Regression analyses	Age differences in reward-seeking followed a curvilinear pattern, increasing between preadolescence and mid-adolescence, and declining thereafter. In contrast, age differences in impulsivity followed a linear pattern, with impulsivity declining steadily from age 10 on. Heightened vulnerability to risk-taking in middle adolescence may be due to the combination of relatively higher inclinations to seek rewards and still maturing capacities for self-control.
Braams, Peters, Peper, Guroglu & Crone (2014) Oregon, USA	The patterns of brain activity for high and low sensation seeking adolescents during reward processing	54 (both genders) aged 12-16 years scored as high or low sensation seekers (below average and above average participants used)	Monetary reward processing task	ANOVAs and fMRI brain activity recordings.	No differences in risk taking behaviour between high and low sensation seekers. Differences observed between groups in brain response to reward feedback during the task. High sensation seekers showed a hypo-response pattern in the absence of reward compared to low sensation seekers (who demonstrated comparable patterns of activity with and without rewards).
DeYoung, Hawes, Civali & Rustichini (2014) Minnesota, USA	Relationship between extraversion and reward sensitivity	90 participants. Unknown demographics	Delay discounting task	ANOVAs and fMRI recordings.	Extraversion (and no other of the Big Five) was associated with neural sensitivity to monetary reward. Provides support for the theory that extraversion reflects reward sensitivity.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
O'Brien, Albert, Chein & Steinberg (2011) Philadelphia, USA	The effect of peer presence on adolescent risk taking behaviour	100 (52 females) aged 18 – 20 years.	Delay discounting task, choose between immediate versus delayed reward	ANOVAs	In the presence of their peers participants demonstrated a greater preference for immediate rewards than when on their own. Adolescents' heightened risk taking adolescents when in presence of friends may be due in part to the effect that peer presence has on their reward sensitivity.
Op de Macks, Moor, Overgaauw, Guroglu, Dahl & Crone (2011) Netherlands	The relationship between pubertal maturation, gonadal hormones, reward processing and risky behaviour	50 (33 female) aged 10-16 years at different stages of puberty	Pubertal Development Scale (Petersen et al, 1988)	t-tests and correlations	Higher testosterone levels was related to an enhanced striatum response to reward. Individual differences in hormones at puberty are related to the way adolescents respond to reward, which can ultimately affect risk- taking behaviour. Results are in line with Nelson's SIPN model which predicts that affective changes (e.g. changes in reward processing are associated with changes in limbic brain regions that are specifically influenced by gonadal hormones.
Telzer, Fuligni, Lieberman & Galvan (2013) Illinois, USA	The effect of heightened reward sensitivity on adolescents performing prosocial activities	32 (18 female) aged 15-18 years old, attending high school	Rule-Breaking subscale of the (Achenbach, 1991), Cognitive Appraisal of Risky Events Questionnaire (Fromme et al, 1997)	Correlations and regression analyses	Heightened ventral striatum activation to prosocial stimuli was related to longitudinal declines in risk taking. Thus the same region that predicts vulnerability for adolescent risk taking may also be protective against risk taking. Providing assistance to one's family was particularly predictive of reduced risk taking in high reward sensitive individuals.

Author, Publication Year and Jurisdiction	Context	Participants	RS and Risky Behaviour Measures	Analytical Methods	Main Findings
Voigt, Dillard, Braddock, Anderson, Sopory, Stephenson (2009) Pennsylvania, USA	Relationship between BIS/BAS and engaging in risky health behaviours	976 (58.4% female) aged 17-69 years old, attending college	BIS/BAS scales and 2007 State Local Youth Risk Behaviour Survey	Correlations	Contrary to expectation, reward-responsiveness served as a protective force against engagement in risky health behaviours (sex, alcohol, drug and tobacco use, safety, inactivity and poor diet).