Risk homeostasis theory - A study of intrinsic compensation.

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Abstract

Risk Homeostasis Theory (RHT) suggests that changes made to the intrinsic risk of environments are negated in one of three ways: behavioural adjustments within the environment, mode migration, and avoidance of the physical risk. To date, this three-way model of RHT has little empirical support, whilst research findings on RHT have at times been diametrically opposed. A reconciliation of apparently opposing findings might be possible by suggesting that extrinsic compensation fails to restore previously existing levels of actual risk in cases where behavioural adjustments within the environment are incapable of negating intrinsic risk changes. This paper reports a study in which behavioural adjustments within the physical risk-taking environment are capable of reconciling target with actual risk. The results provide positive support for RHT in the form of an overcompensation for the intrinsic risk change on specific driver behaviours.

KEYWORDS: Risk, Accident Loss, RHT, Compensation, Simulation

Introduction

Risk homeostasis theory, or RHT (Wilde, 1982a, 1982b, 1988, 1989), is one of several theories that stress the importance of human factors in interventions aimed at improving environmental risk. In essence, the theory holds that it is the target level of risk, rather than the absolute level of environmental risk, that determines accident loss . RHT therefore posits a population-level closed loop process in which target and actual risk are compared. Wilde conceptualises target risk as the level of risk that the individual deems acceptable. This level is set by the values of four relevant 'utilities': the and benefits of relatively cautious behaviour, the costs and benefits of relatively dangerous behaviour. If one or more of these utilities change, a corresponding change in target risk can be expected to follow. Risk homeostasis, then, is not about risk taking for its own sake, but rather, presents a picture of risk-taking behaviour built on the concept of utility. (We use the preposition *on* rather than *with* to imply that any falsification of the role of utility in determining risk-taking behaviour in response to a change in the level of intrinsic risk, would be bound to leave the theory in a state of conceptual ruins.)

How might one evaluate the claims made by the proponents of RHT? Four approaches have so far characterised the debate. One approach has been the construction of theoretical/cognitive and mathematical modelling (O'Neill, 1977). This approach involves predicting behaviour from utility terms. O'Neill introduces here the notion of a *negative* utility for the costs of accidents in his model. The difficulty with such modelling is that it has so far proved impossible to derive from it very much in the way of testable hypotheses. The models are not only unverified, they would seem to be unverifiable.

The second approach is to examine accident loss statistics before and after an intervention. Perhaps the best example here, and certainly one that has attracted a great deal of attention, is that of compulsory seat-belt wearing (Adams, 1985; Bohlin, 1967, 1977; Bohlin and Aasberg, 1976; Chodkiewicz and Dubarry, 1977; Foldvary and Lane, 1974; Hurst, 1979; Lund, 1981). This approach suffers from a lack of experimental control: after some interventions, it is often difficult to establish what risk-relevant factors have changed, other than the intervention itself. Next, there is the quasi-experimental study (see Lund and Zador, 1984 and Smith and Lovegrove, 1983). This involves taking measures of specific driver behaviours, such as speed, headway and so on, before and after some local intervention aimed at improving intrinsic safety. There are difficulties with this approach too. First, just as in any quasi-experimental methodology, and in common with the analysis of road-accident statistics, it can be difficult to disentangle cause from effect. Second, as highlighted by Hoyes, Dorn and Taylor (1992), in common with the analysis of accident loss statistics, it only addresses half of the RHT question - the consequences of a change in intrinsic risk in terms of accident loss. Whether individuals are characterised by a target level of risk, and whether this target can be shifted via changes in relevant utilities, are questions that the quasi-experimental study can never answer.

The fourth methodology associated with RHT is the simulation approach. Many attempts have been made to understand risk homeostasis theory in simulated risk-taking environments (Mittenecker,1962; Näätänen and Summala , 1975; Veling,1984; Wilde, Claxton-Oldfield and Platenius, 1985; Tränkle and Gelau, 1992). Hoyes *et al*. (1992) argue that all these early simulations are flawed in that they rely for their validity on generalisation from non-physical to physical risk-taking, and that this assumption is unwarranted. Moreover, they point out that the awarding of points as a substitute for the real utility of a risk-taking experience is both conceptually inappropriate and laden with demand characteristics. Thus, the simulated examination of RHT undertaken by Hoyes *et al.* involved some attempt to simulate *physical* risk.

It is important, now, to recall that in Wilde's (1982a, 1982b, 1988) model of risk homeostasis theory, it is suggested that the mechanism by which an equilibrium state of accident loss is said to take place involves three separate behavioural choices (Wilde, 1988, proposition 2). When a change is made to the level of environmental risk, the risk-taker may respond first by behavioural adjustments *within* the risk-taking environment. In a road traffic environment, this may involve driving faster or slower, overtaking less frequently, reducing the marginal temporal leeway at which an overtake will be attempted, increasing or decreasing attention, and so on. A second route to the achievement of homeostasis is what one might term 'mode migration' - changing from one form of transport to another. For example, a motorcyclist may decide, in the light of inclement weather, to take a train into work rather than risk collision on his or her motorcycle. Finally, if the level of target risk and the level of actual risk cannot be reconciled either within the risk-taking environment, or through changing from one mode of transport to another, the individual may elect to stay at home and not to undertake any journey. This possibility, for the purposes of this paper, will be referred to as 'avoidance'.

So, the achievement of risk homeostasis can, according to its originator, be brought about in three ways. These can be labelled *behavioural adjustments within the environment, mode* *migration*, and *avoidance*. Out of this comes a realisation that all of the above attempts to examine RHT in simulated environments have, in fact, looked only at one possible pathway to homeostasis: behavioural adjustments *within* the environment. Interesting though this question is, it would appear to answer only one third of the risk homeostasis model.

To examine the question of whether RHT might receive active support in an environment in which the further degree of freedom exists to restore the correspondence of target with actual risk via the adjustment of specific driver behaviours, the Aston Driving Simulator was used. Indirect manipulations were made to the temporal leeway allowed for overtaking manoeuvres. In such a study, adjustments to intrinsic risk can, unlike study 1, be negated by behavioural adjustment within the environment (eg, overtaking less frequently, adopting new decision rules, etc.).

The study of overtaking behaviour is not new (see Crawford, 1963). Much attention has been given to the issue of overtaking margin and type of vehicle. It has, for example, been shown that drivers of small cars often adopt riskier headways (Wasielewski, 1981), although Evans and Rothery (1976) provide evidence which suggests that findings like that of Wasielewski might be at least partly explained by differences between driver groups. Whether a correlational fallacy or not, it is known that drivers of powerful cars tend to make fewer errors when overtaking (Kaukinen, 1967).

Harris, Brindle and Muir (1986) point out that the power of a vehicle is of less interest than the power to weight ratio. They found that HGV drivers specifically, and generally drivers of low power to weight ratio vehicles, adopt riskier overtaking strategies. By contrast, drivers of high power to weight ratio vehicles were shown to adopt relatively safe overtaking strategies. Unfortunately, Harris *et al.* were unable, just as previous researchers, to eliminate the possiblity that overtaking differences may have been attributable to driver-related, rather than vehicle-related, factors. An advantage of a counterbalanced, repeated-measures design, such as the one reported here, is that the same 'drivers' can be asked to participate under different overtaking conditions, thus eliminating driver-related overtaking factors.

Method

Participants

Seventy participants took part in this study. Thirty-five participants were aged between 18 and 30 years; the remaining thirty-five participants were aged between 45 and 60 years.

Equipment

The Aston Driving Simulator (see Glendon, this volume) was used for this study.

Design and Procedure

All participants were given two experimental trials. In condition 1, cars in front of the simulated driving position moved at speeds of between 20 and 30 mph. In condition 2, the cars in front of the simulated driving position were moving at speeds of between 30 and 40 mph. Condition order was counterbalanced. Given that the speed of on-coming cars was held constant across these two conditions, condition 2 can be considered environmentally the riskier condition in that overtaking times (together with error margins) would be reduced. If overtaking behaviour were to remain unchanged between the two conditions, and if no other behavioural compensation were to occur, one would predict greater accident loss on condition 2. However, this can be considered a very local change to environmental risk and one that could be compensated for, in theory at least, by changes to the overtaking-decision threshold, commensurate with the change in risk. Measures were therefore taken to establish whether the changes in behaviour were indeed either local in themselves or consequences of local changes to environmental risk (knock-on effects of local adjustments). Measures were also taken to establish the extent to which a more general compensation process might be pursued, along with the usual measures reflecting accident loss: other-vehicle collisions and kerb-collisions.

Results

1. The overtaking (specific) measures

Where the environment was characterised by higher levels of environmental risk, this was associated with fewer other-vehicle collisions, fewer successful overtakes, and fewer end-pull-backs (aborted overtakes). It was associated with more kerb collisions whilst overtaking, though not significantly more.

Related *t*-tests were carried out on all the above comparisons. Risky overtakes occurred on significantly fewer occasions on the condition of high environmental risk, t=2, p=.024. This is shown in figure 1. For the purpose of this experiment, a risky overtake was defined as one in which an oncoming car was visible from the driver's position when the participant pulled out to overtake. The comparison of aborted overtakes produced *t*=3.15, p=.0012. This comparison is shown in figure 2. For the number of 'other vehicle collisions whilst overtaking' comparison the *t* value of 1.70 was significant (p=.0464). Kerb collisions whilst overtaking produced a *t* value of <1, NS, as did the comparison of total overtakes.

INSERT FIGURE ONE ABOUT HERE

Figure 1 : Environmental risk and mean number of 'risky' overtakes

INSERT FIGURE TWO ABOUT HERE

Figure 2 : Environmental risk and mean number of aborted overtakes

Successful overtakes too occurred on fewer occasions in the condition of high environmental risk, *t*=1.957, p=.0272. Finally, the comparison of mean leeway was on the margin of significance with *t*=1.594, p=.0577.

2. The non-overtaking (general) measures

Related *t*-tests were carried out for a range of general indicators of driver behaviour, across the two conditions of environmental risk. First, the comparison of road position (position relative to centre white line and kerb) across conditions was not significant (*t*<1, NS). It has been argued previously (Hoyes *et al.*, 1992) that road position can be considered a measure of tracking performance, and therefore, by inference, an indirect measure of attention and specific motor skills. Since benefits may well be gained from maintaining reduced levels of attention, one could look upon this as a general measure of compensation, not local to the change in environmental risk. From this it would seem that arguments for a more general form of compensation related to attention would not be supported.

The second of these measures to be examined was *distance to car in front*.. This gave a related-t value of 2.67 (p=.0024). This finding is difficult to interpret. On the one hand, the behavioural adjustment of pulling closer to the car in front does not facilitate the local need for adjustment. However, when one looks more closely at the behaviour one sees that the finding is in fact the reverse of that which would be predicted by RHT. Rather than respond to the change in environmental risk by increasing the 'safety' gap, drivers were, it would appear, making an already riskier situation (environmentally speaking), more risky still (behaviourally speaking) by moving closer to the car in front. Perhaps then this finding can be explained in terms of its being an almost mechanical consequence of the change to environmental risk, or rather, its specific manifestation: when drivers are prevented from overtaking a car, they tend to move closer to the car preventing the manoeuvre. This behaviour can therefore not be considered a general case of behavioural compensation, but is probably best explained outside of a compensation framework.

Mean speed too was examined and proved significant with a *t* value of 8.98, p<.0001. The effect of environmental risk on this measure is shown in figure 3. Although one might again imagine that this finding would be difficult to interpret (speed adjustments might reflect a general compensation, or may just be a trivial consequence of not being able to overtake so frequently, or having to overtake at higher speeds) the direction of the difference is again able to settle the matter. The condition of high environmental risk was associated with greater speeds. Far from compensating through this pathway, participants actually made things worse.

INSERT FIGURE THREE ABOUT HERE

Figure 3 : Environmental risk and mean speed in simulated mph.

Accelerator mean position, correlated with speed, of course, showed no effect of environmental risk (*t*=1.038, NS). In fact, the correlation between accelerator travel and mean speed, whilst strong, perhaps does not quite reach the strength one might imagine - r=.505 (SD of mean speed across conditions = 6.55; SD of mean accelerator travel across conditions = 14.21; covariance of *xy* = 47.04). Again, this general pathway moved away from, rather than supporting, homeostasis.

Brake was significantly different across conditions (*t*=4.53, p=<.0001). Again, this result is perhaps best seen as a mechanical consequence to changes in local environmental risk. Where overtaking is made more difficult, drivers will have more often to abandon an overtake, and this may well involve greater use of the brake.

The mean position of the steering wheel also differed between conditions (*t*=-3.97, p<.0001). On the surface this might reflect either nothing more complicated than a greater number of overtakes on one condition rather than another, or a reflection of relative attention level. Since differences in the number of overtakes and attempted overtakes must necessarily be reflected in steering wheel position, and since *position on road* did not provide evidence of attentional differences across conditions, the former suggestion has perhaps more appeal.

Finally the two measures reflecting accident loss should be considered. On the condition of greater environmental risk there were fewer other-vehicle collisions (hitting another car) and fewer kerb collisions (hitting the kerb) than on the condition of low environmental risk. In the case of other-vehicle collisions (the more serious measure of accident loss) this difference was significant (*t*=3.66; *p*=.0002). This is shown in figure 4. The effect of environmental risk on kerb collisions is shown in figure 5.

INSERT FIGURE FOUR ABOUT HERE

Figure 4 : The effect of environmental risk on mean number of other-vehicle collisions

INSERT FIGURE FIVE ABOUT HERE

Figure 5 : The effect of environmental risk on mean number of kerb collisions.

The strong implication from the measures reflecting accident loss seems to be that behavioural compensation can occur in the short term and that initial adjustments may be characterised by their tendencies towards being over-compensatory. In predicting that initial compensation can be perfect, imperfect surplus or imperfect deficit, RHT really says only that in the short term anything can happen. In other words, any finding could have been reconciled with RHT. The findings on other-vehicle collisions, however, are far more satisfactory than the open prediction in that they (i) provide active support for compensation and; (ii) do so at very low alpha levels.

Discussion

This experiment is arguably the most significant simulation study of RHT for several reasons. First, in providing evidence of significant initial over-compensation, the study has provided the clearest findings so far in support of RHT. In direct opposition to an engineering perspective, this study showed that on the condition of high environmental risk, there were fewer collisions, both with the kerb and with other vehicles. Whereas RHT has evidence to support it from field studies involving crude before-and-after designs, this study provides evidence for RHT in a tightly-controlled, laboratory study with possible confounding variables removed.

Second, the study shows that the investigation of RHT hypotheses in a simulated physical risk-taking environment can be successful to the extent of bringing about an effect. If Wilde is correct in his assertion that road-users are characterised by a target level of risk, which is maintained when changes in environmental safety are introduced, then this study would indicate that this same process can be successfully reproduced in a simulated environment.

Third, the study is interesting in that it provides evidence for a movement towards homeostasis within a very short time span - when environmental risk changed, participants drove for a period of just ten minutes. Within this period a significant adjustment took place. This leaves the question of how participants were able to compensate so quickly. Two, not necessarily mutually exclusive, explanations could account for this. The first of these is the possibility that participants recognised and compensated for the risk change as soon as that change was apparent - as soon, that is, as they realised that overtaking would be more or less hazardous if relevant behaviours were maintained at their previous level. The second possibility is that information regarding accident loss, such as other-vehicle collisions, kerb collisions or near-misses, must be given to participants before compensation can occur. These two possibilities could be crudely labelled as, respectively, open- and closed- loop explanations.

A fourth aspect of this study that makes it interesting is its apparent justification of the attention given to the particular behavioural pathways that carry the effect. It would seem from these that where a change in environmental risk is highly specific, such as the time margin allowed to overtake vehicles, this specific risk change is responded to by participants by equally specific behaviours - behaviours, in other words, that could be said to be *relevant* to the environmental risk change.

The experiment has implications concerning the development of an alternative methodology for RHT. The evidence reported here seems to suggest that although the time-scale of homeostasis in real physical risk-taking situations spans months or even years (see Wilde 1988, 1989), this may be nothing more than a consequence of delayed feedback. As long as immediate feedback of errors and of the change in intrinsic safety can be provided, a simulated environment may be entirely appropriate for investigating compensatory behaviours over a very short time span. In other words, collapsed experience must be possible for effective investigation to take place.

A word or two needs saying about the way in which environmental risk was operationalised in this study. In order to make the risk change specific to some particular behaviours, the environmental risk factor of temporal leeway was operationalised. However, as stated in the method section, this manipulation was not direct, as would have been the case, say, had the simulator's acceleration capabilities been altered, but was instead indirect through the manipulation of the average speed of cars on the simulator's driver-side of the road. When the average speed was increased, the temporal leeway was, indirectly, reduced. But can such an indirect manipulation really be said to change environmental risk? A critic might point out that when cars in front were moving at greater speeds, the driver had a much reduced *need* to overtake them, and thus, it may even be that the direction of the change in environmental risk is the opposite to that reported here. A number of arguments can be used to rebut this criticism and suggest that the indirectly reduced temporal leeway condition really did represent a reduction in environmental risk:

1. Two participants were run and interviewed informally in a pilot study. Both these participants agreed that the reduced temporal leeway condition was in their view the more hazardous. In the case of the Swedish experience in changing the side of road on which road-users were asked to drive, it must be remembered that one side of the road is *intrinsically* no more dangerous than the other. What made the Swedish case relevant to the RHT debate was that those affected by the change had some *subjective* experience of risk change. Since workers in RHT from both sides of the debate are in agreement that the Swedish experience is relevant to the homeostasis question because of this subjective

experience, agreement by participants in the pilot study that the reduced temporal leeway condition did represent higher risk might be said to be justification enough.

2. For the indirect manipulation of leeway to fail in changing environmental risk in the predicted direction, participants must have a reduced need to overtake at the higher speeds. Extensive pilot work from other studies involving the ADS suggests that this tendency is subject to floor effects. So long as the maximum speed of the car being followed is equal to or less than 40 mph (as was the case in this study) participants will be characterised by overtaking behaviour.

3. The reduced temporal leeway condition allows greater speeds to be reached for the same level of overtaking. Since speed is known to be correlated with risk, this too should lead to the conclusion that the reduced temporal leeway condition is environmentally the more hazardous.

4. The measure of mean leeway is independent of the number of times participants overtook other vehicles. If speed increases in the vehicles being followed led to reductions in the number of overtakes, this measure takes this reduction into account. The measure of mean leeway is on the margin of significance (p=.0577).

In fact the indirect nature of this risk change was deliberate. To have manipulated leeways directly through acceleration capability would led to delayed feedback and a number of inevitable collisions during learning. The indirect manipulation was an attempt to provide almost concurrent feedback. Moreover, it was felt that this indirect approach had greater ecological validity. We often find ourselves with less time of overtake other vehicles because the vehicles ahead of us are driving faster; we rarely suffer a reduced temporal leeway through a failure of our vehicles to accelerate to the same speed in the same time that they did a few moments ago. In essence, a direct manipulation of temporal leeway would have involved just this.

Conclusions

The suggestion that adjustments capable of achieving a correspondence between target and actual risk is contingent upon the extent to which behavioural adjustments within the environment are possible receives support in the context of the study reported here. However, further research is needed in establishing whether such a model might explain actual accident loss in response to environmental risk improvements.

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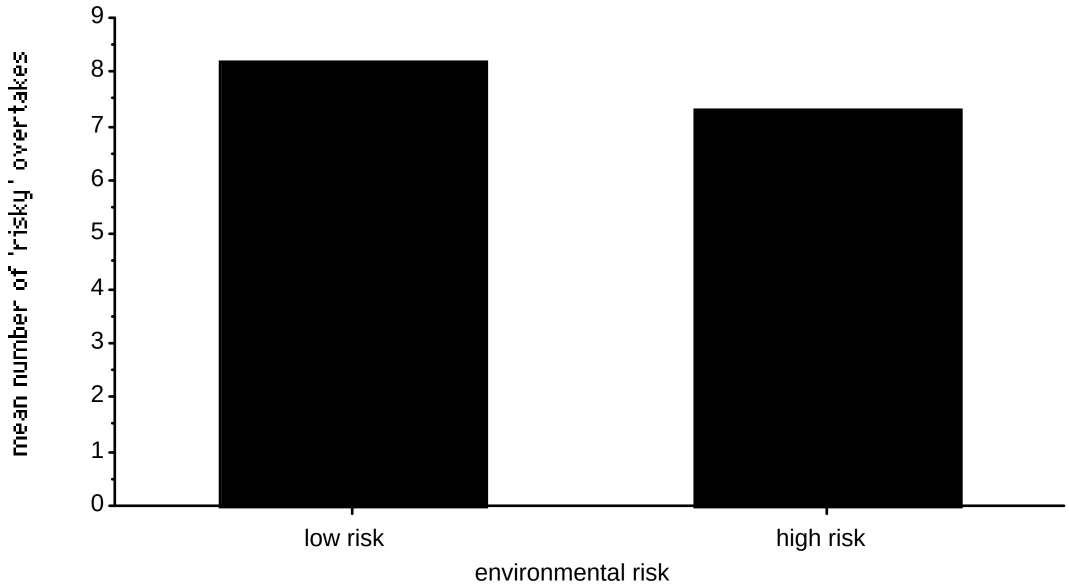

mean number of 'risky' overtakes
0
1
2
3
4
5
6
7
8
9
low risk
high risk
environmental risk

FIGURE ONE

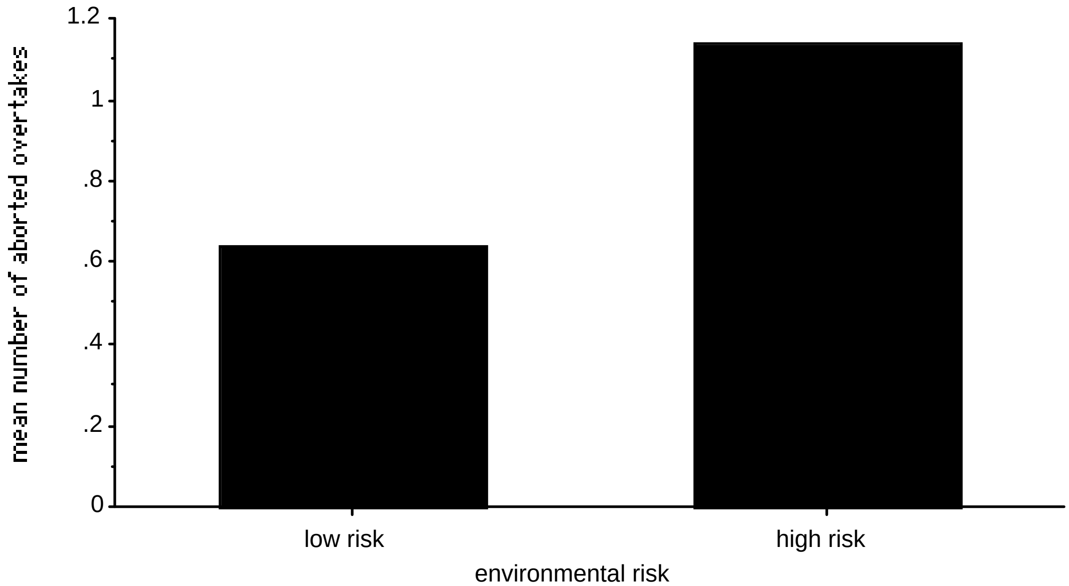

mean number of aborted overtakes
1.2
1
.8
.6
.4
.2
0
low risk
high risk
environmental risk

FIGURE TWO

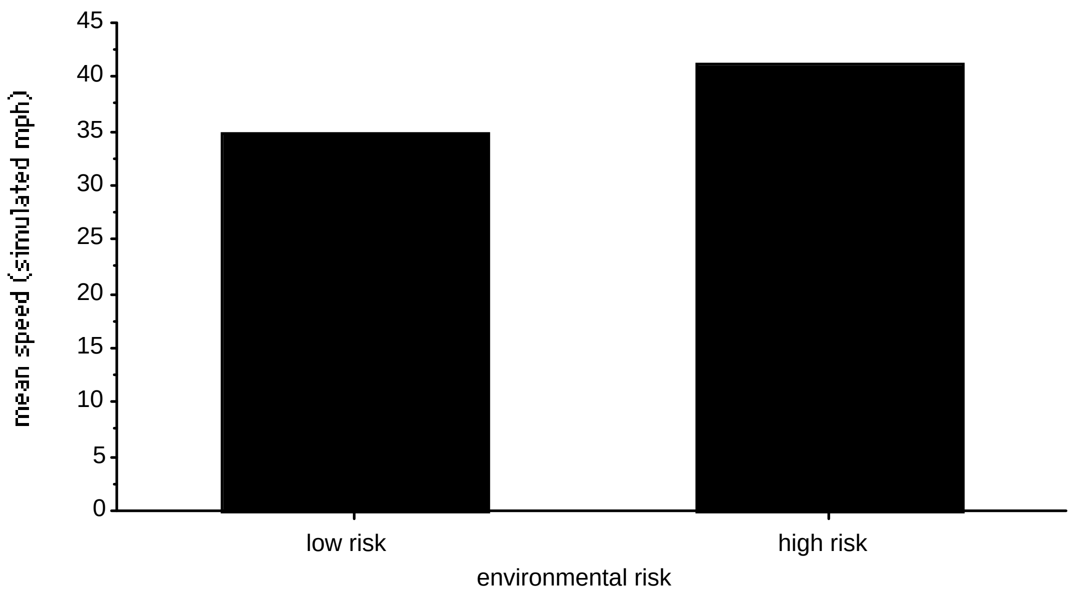
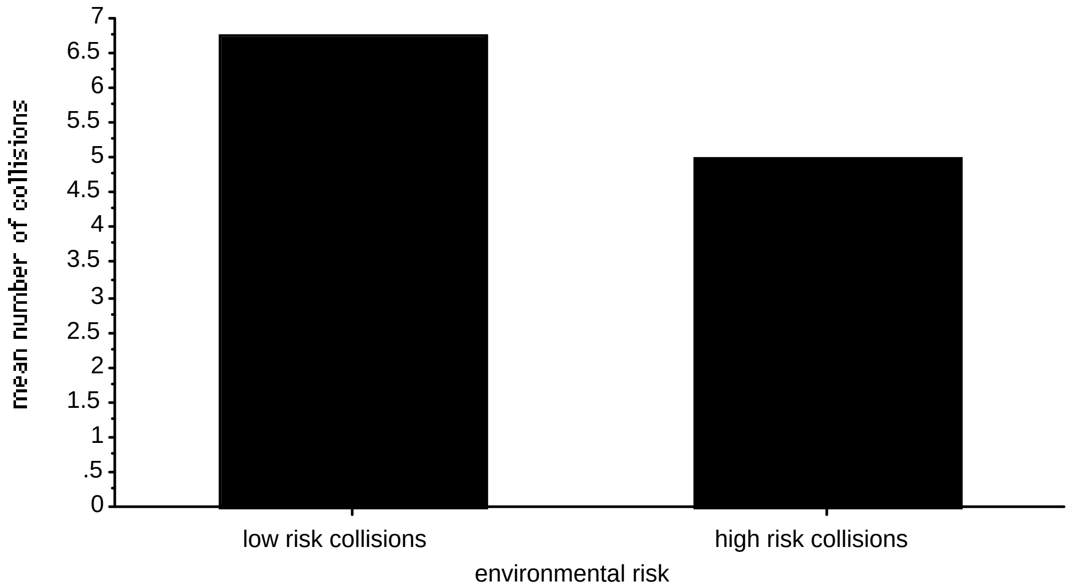


FIGURE THREE



mean number of collisions
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
low risk collisions
high risk collisions
environmental risk

FIGURE FOUR

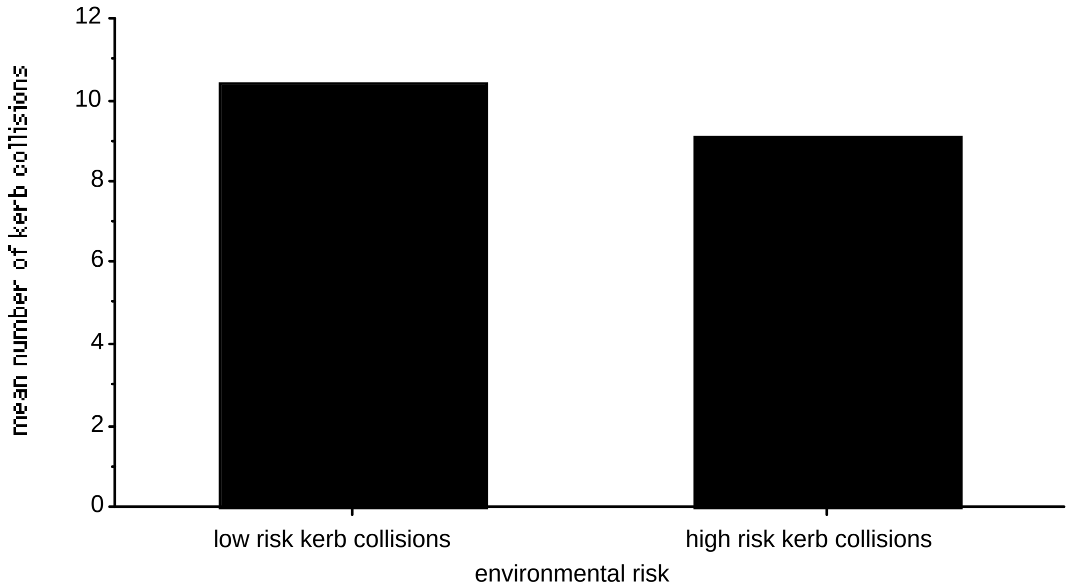

12
10
8
6
4
2
0
mean number of kerb collisions
low risk kerb collisions
high risk kerb collisions
environmental risk

FIGURE FIVE