Collision Design

Joe Marshall
Paul Tennent
Christine Li
joe.marshall@nottingham.ac.uk
paul.tennent@nottingham.ac.uk
christine.li@nottingham.ac.uk
Mixed Reality Lab, School of Computer Science, University of Nottingham
Nottingham, UK

Claudia Núñez Pacheco
Rachael Garrett
claudia2@kth.se
rachaelg@kth.se
KTH Royal Institute of Technology
Stockholm, Sweden

Vasiliki Tsaknaki
vats@itu.dk
IT University of Copenhagen
Copenhagen, Denmark

Kristina Höök
khook@kth.se
KTH Royal Institute of Technology
Stockholm, Sweden

Praminda Caleb-Solly
Steven Benford
praminda.caleb-solly@nottingham.ac.uk
steve.benford@nottingham.ac.uk
School of Computer Science, University of Nottingham
Nottingham, UK

LIKELIHOOD	SEVERITY	ACCEPTABLE LITTLE TO NO EFFECT ON EVENT	TOLERABLE EFFECTS ARE FELT, BUT NOT CRITICAL TO OUTCOME	UNDESIRABLE SERIOUS IMPACT TO THE COURSE OF ACTION AND OUTCOME	INTOLERABLE COULD RESULT IN DISASTER
	IMPROBABLE UNLIKELY TO OCCUR	LOW - 1 -	MEDIUM - 4 -	MEDIUM - 6 -	HIGH - 10 -
	POSSIBLE RISK WILL LIKELY OCCUR	LOW - 2 -	MEDIUM - 5 -	HIGH - 8 -	EXTREME - 11 -
	PROBABLE RISK WILL OCCUR	MEDIUM - 3 -	HIGH - 7 -	HIGH - 9 -	EXTREME - 12 -

RISK RATING KEY			
LOW	MEDIUM	HIGH	EXTREME
0 - ACCEPTABLE	1 - AS LOW AS REASONABLY PRACTICEABLE	2 - GENERALLY UNACCEPTABLE	3 - INTOLERABLE
OK TO PROCEED	TAKE MITIGATION EFFORTS	SEEK SUPPORT	PLACE EVENT ON HOLD

Figure 1: An example risk matrix. Risk matrices are a widely used way of representing risk and prioritizing required mitigations. The colouring of a risk matrix belies an underlying assumption that increased risk is inherently bad, which we dispute in this paper.

ABSTRACT

Collision, "the violent encounter of a moving body with another", is poorly understood in HCI. When we discuss people colliding with the physical artifacts we create, or colliding with each other while using our systems, this is primarily treated as a hazard, something which we should design to avoid. However many other human activities involve situations where deliberate exposure to risk of collision may in fact have positive aspects. In this paper we discuss how the 'risk matrix', a widely used risk-management tool, which categorizes risks in terms of likelihood and severity, may limit interaction in unintended ways. We discuss reframings of this matrix in relation to design concepts of 'adventure', 'disempowerment/agency' and 'consent'. and show that a range of design spaces for collisions exist which may be fruitful to explore.

CHI EA '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9422-2/23/04.
https://doi.org/10.1145/3544549.3582734

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models.**

KEYWORDS

collision, human-robot interaction, risk

ACM Reference Format:
Joe Marshall, Paul Tennent, Christine Li, Claudia Núñez Pacheco, Rachael Garrett, Vasiliki Tsaknaki, Kristina Höök, Praminda Caleb-Solly, and Steven Benford. 2023. Collision Design. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3544549.3582734

1 INTRODUCTION

A collision is a forceful coming together of two objects, a "violent encounter of a moving body with another"[46]. In this paper we differentiate between a collision and lighter contact by the potential for short or long term physical harm. For example if two people gently touch each other, it is unlikely to cause physical pain. This is not a collision, and we don't talk about it here. If one punches the other, this collision will cause immediate pain, which may or may not be followed by longer term effects such as injury, bruising, or even death. Similarly if a robot vacuum cleaner pushes up to a wall gently and senses a push on its bumper then turns away, that isn't a collision as we discuss here, whereas if a robot crashes hard into a piece of furniture and damages the furniture or itself we are into collision territory.

So, why are collisions interesting in human computer interaction? Firstly, an increasing part of interaction between computers and the world occurs in ways in which the computational system is physically embodied in some way, in forms such as autonomous vehicles, drones and robots. Secondly, such embodiments are increasingly taking place in relatively uncontrolled physical settings – autonomous ground vehicle systems are no longer restricted to highly controlled and segregated automated railway systems, but are instead driving real cars in real cities. Robots are no longer constrained to behind safety shields in factories, but are collaborating with human factory workers. Mobile robotics is no longer restricted to tasks such as remote inspection, but instead is taking an active role in close-contact activities such as assisting people in self-care activities. Collision is an inevitable corollary of this increased physical presence of computing in uncontrolled real-world settings. Whether it be autonomous cars crashing into people or their environment, or people ganging up to attack public security robots or shoot down drones, collisions with computer systems are here and demand our attention.

It is possible to argue that the only thing we as technologists should be doing is working out how to avoid collisions. Clearly if we believed this, it would make for a very short paper. However, there are a wide range of human endeavours such as childhood play and contact sports in which collision or risk of collision forms an active and positive element, acting as an entertainment, a learning tool, a motivation, a way of measuring skill and prowess and so on. By choosing to treat collisions purely as a risk to be mitigated, we believe that we neglect a potentially interesting and fruitful design space.

In order to demonstrate how reframing risk as opportunity can create space for design, we adopt here a widely used categorisation of risk which has been widely applied to areas involving physical risk such as human robot collisions. This splits risks into a two dimensional matrix based on severity plotted against likelihood of occurrence. Whilst this is open to some criticism, variations of this 'risk matrix' are in practice widely used. We argue that underlying this risk matrix is a fundamental assumption that risk is in itself negative; we reframe this in three different ways: firstly we discuss how if one is considering 'excitement' or 'thrill' of an activity, one may revalue the potential for physical collision and risks of harm; secondly, we discuss how focus on minimizing risk may constrain people's freedom, and ways in which taking controlled risks may actually empower people to live around technology; finally, we discuss how consent fundamentally alters how we might design for risk of collision.

These reframings demonstrate that as well as posing risk of harm, collisions also present a rich and nuanced design space for new embodied human-computer experiences, allowing us to work with types of human experience that would otherwise be inaccessible to designers, and allowing users to choose to take risks rather than be constrained by engineered safety.

2 RELATED WORK

We discuss 4 areas of related work; firstly, we introduce risk matrices, which we use as a key framing for our consideration of collision in the rest of the paper. We follow this with discussions of collision in respect to robots, HCI in general, and collision in human sports and play.

2.1 Risk Matrices

A risk matrix (see Figure 1) is a widely used way of modelling risks in projects and systems. It has been used in many areas including the military [17], construction [40], human-robot safety [42], and is part of international safety standards ([24]). In a risk matrix, the risk level of an adverse event is are categorised on two scales, firstly the likelihood of an event occurring, and secondly the severity, or impact of that event occurring. This can be used to understand a) whether a risk requires mitigation, and b) how to prioritise a range of different potential risks. As a widely used tool, risk matrices have been subject to some criticism, in particular that they have a limited resolution leading to errors in categorisation of risk and ultimately in poor decision making around risk [2, 55]. Having said that however, they are by far the most widely used structured risk management tool, and as such other authors have suggested ways of effectively using them, such as by using linear scales as opposed to discrete categories for each variable [13]. Risk matrices are traditionally presented with colours representing overall risk level, with low values of both severity and likelihood being coloured green, medium and high values of either going yellow, and with the highest risks, those that are high severity and likelihood, being coloured red.

2.2 Robots and Collision

In robotics, there has been a focus on avoiding collisions between robots and humans. This is understandable when industrial robots are placed in close proximity to human operators. Lasota et al. summarize this well in their extensive survey of work in the area:

> "In simple terms, in order for HRI to be safe, no unintentional or unwanted contact can occur between the human and robot. Furthermore, if physical contact is required for a given task (or strict prevention

> of physical contact is neither possible nor practical) the forces exerted upon the human must remain below thresholds for physical discomfort or injury. We define this form of safety in HRI as physical safety." [35]

Ensuring the safety of such robots is done in several ways – avoiding collisions by detecting any obstacles in their path or trajectory, constraining velocity and position of robots or humans to allow time for relocation, planning of motion paths to avoid humans, and even avoidance by predicting human motion. There are also 'post-collision' safety methods, in which the robot changes behaviour once it detects a collision has occurred [35]. If the robot is small enough, for example a cleaning robot, low impact collisions with objects and humans become a strategy for detecting then moving away from them.

Recent robotics advances require physical collaboration between robots and human operators, for example assistive robots at home. In this situation, contact between robot and operator or end-user is inevitable, such as a dressing-support robot [12]; however focus is primarily on keeping this contact 'safe'; i.e. on limiting force involved in contact and avoiding any collisions with humans [45].

Autonomous mobile robots, from vehicles, to delivery robots and tele-presence robots, are increasingly finding their way into everyday settings. Research into autonomous robot navigation has turned to the question of social acceptability. Not only should robots avoid obstacles, but they should consider comfort, naturalness, and sociability of their manoeuvring [34], treating people as social beings and not as mere obstacles [31], for example by respecting their personal space [49]. Proposed solutions include algorithms based on the Social Force Model [21, 31, 31], that balances attractive forces exerted by navigation goal points with repulsive forces emanating from nearby humans. However, this can result in indecisive collision adverse robots becoming stuck in local minima positions, especially in crowded spaces [53]. Autonomous systems may also exhibit less desirable social behaviours such as hesitancy, dithering, and poor social signalling. Brown's [9] study of partially self-driving Tesla and Google cars reported how their inability to interpret and convey subtle social cues that arise when deliberately leaving or closing gaps for other drivers led to some confusion.

2.3 Collision in HCI

Whilst HCI largely avoids extreme collisions, in our previous work, we considered 'brutal' games inspired by contact sports and martial arts [41], where we built multiple games where players were deliberately encouraged by computer systems to push and crash into each other.

Virtual reality (VR) research also considers collisions. The first thing users are told to do when setting up a headset is to 'clear the room' so they do not hit anything. However, that does not mean that there is no physical component to VR. Foundational work on the concept of presence has tried to isolate factors that can make a virtual experience feel real, including haptics and virtual collisions [14, 30, 37, 51] – however 'collisions' here typically refer to delivering a sense of touch (i.e. haptics) – making objects and environments feel more real by giving them physical presence, rather than focusing on deliberate or accidental collisions.

The emergence of room-scale VR in which participants walk freely to explore a virtual environment has led to the development of widely adopted chaperone systems that try to prevent them colliding with physical walls, furniture and other objects [23]. Recent explorations of passive haptics and superimposed reality have placed proxy physical objects at locations of virtual objects so participants can physically interact with them while also avoiding collisions with unexpected physical objects that are not proxies [1, 33]. We note that in [54] authors cite accidental collision of a headset with a window as evidence of immersion (users were so immersed, they forgot they were wearing a headset).

2.4 Collision in Play

Multiple authors [10, 20, 47] describe the importance of risky play in childhood. Such play can involve risk of physical injury from heights, speed, and objects,. Playground games often involve forceful physical contact, such as knocking people down or grappling them. Such play is inextricably linked to collisions, from falls or injuries from the play environment, to touching and hitting in chasing games such as Tag, to full body collision and tackling in games such as British Bulldog [50]. Though individuals have different tolerance levels, risky play is universally sought after and has been shown to help not only develop physical fitness, but also emotional and social skills such as self-regulation, empathy and problem solving [10, 47].

For many, the desire to collide persists into adult life, such as in sport. Interestingly, participation in such activities is not shown to be correlated to levels of aggression [29, 32], suggesting that collision may be an enjoyable thing in and of itself. They obviously carry a risk of causing pain and suffering. However, work on acute and chronic pain show that pain is not merely a physical phenomenon resulting from bodily harm, but a somatic experience significantly influenced by thoughts, emotional state, and context [27, 28, 43]. Furthermore, there is evidence pointing to extensive overlap in neurological processes and structures between pain and pleasure [36]. In cases such as sport, pain can be rewarding both at the time, and in retrospective enjoyment of having overcome it. [8].

As well as participating in these collisions, such activities are also highly exciting for spectators. In the case of spectating of collisions, there is strong evidence that people enjoy both the vicarious thrill of seeing someone taking extreme risks and avoiding collision, but also there is pleasure to be had in spectating a bad collision; as seen in large audiences of contact sports such as boxing. and also evidenced by the ongoing popularity of video compilations of crashes, which distill sports down to purely the moments of collision, for example Ride magazine's "worst skateboarding slams" video has 4.2m views [39] , a popularity only surpassed by a small number of their videos of world famous skater Tony Hawk.

3 REFRAMING RISK MATRICES

In this section, we characterise user experience of collision based on the two axes of a risk matrix, severity of collision and likelihood of collision. As recommended by Duijm et al [13] we treat each axis as a scale, rather than a set of discrete values; this aims to avoid issues described above of unclear identification of what underlies different

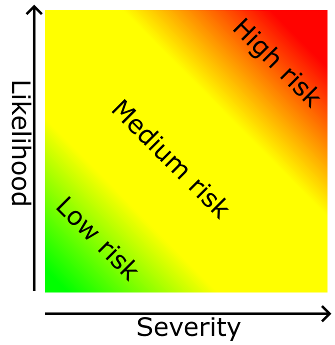

Figure 2: In a traditional risk-based framing, as either of collision severity or collision likelihood get higher, a risk is worse and more in need of mitigation. In this framing, the lower our risk of collision is on either axis the better.

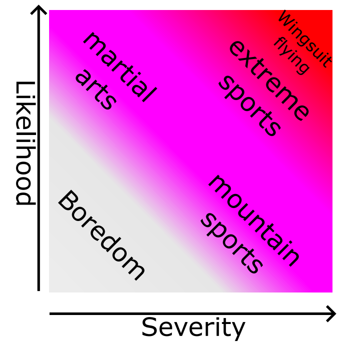

Figure 3: If we frame collisions with respect to 'adventure' or 'excitement', designs with low severity and low likelihood of collisions do not offer much in the way of excitement. As potential severity increases, we have a situation analogous to roped rock climbing, where a part of the adventure is in safely avoiding extremely severe collisions caused by falling from heights. Conversely, as we increase likelihood of collision, we get a situation more like martial arts or other contact sports, where people are unlikely to die, but there is an element of adventure to be had negotiating repeated collisions with other people or the environment. If both likelihood and severity increase, we move into the domain of extreme sports, which offer high thrills in return for high levels of risk taking. At some point on the scale, the risk becomes so high that it may go from being experienced as adventure to being almost analogous to suicide; clearly this level of risk differs between people, with some of the most dangerous of extreme sports such as wingsuit flying being only accessible to those with extremely high tolerance of risk.

values, and we believe is more suitable for use of these axes as a design tool. As such, our first scale measures *severity of collision*, which relates to the impact of a potential collision, ranging from no impact at one end of the scale, to extreme and lasting pain or even death at the high end. The second scale, *likelihood of collision* ranges from extremely unlikely to occur at one end up to definitely going to occur at the other.

In a traditional risk-management framing of these scales, we would be able to apply a simple calculation to prioritise collisions, with greater likelihood or greater severity collisions being higher priority for risk-reducing interventions, and those of both high likelihood and high severity being treated as the most high priority (Figure 2)

In this section we look at what happens if we take a different view on collisions, that collisions may be something which we deliberately design for. We demonstrate the potential of this by looking at three different reframings of our two scales; with each reframing it is clear that different areas on our two dimensional collision axes offer differing benefits and/or risks, beyond the simple value calculations implied by use of risk-management framing.

3.1 The Adventure Matrix

Many entertainment activities involve an element of 'adventure' or 'excitement' which is mediated by collision or the risk of collision. For example in extreme sports such as downhill mountain biking, the excitement of negotiating obstacles at speed or doing large jumps carries an inherent risk of crashing and colliding with the terrain. This risk of collision is a key element of the thrill of such activities; riders will deliberately choose to ride steeper or tighter trails and do bigger tricks, trading increased risk of crashing for the thrilling sensations of increased speed and greater forces. Further to this, with such risk taking comes the sensation of 'cheating death', the thrill which can be had from knowing that you are at risk of a crash, but are using your skill to stay in control. If we look at sports where collision is an inherent part of the activity, we can again see that excitement and adventure can be had from collisions; for example in the sport of roller-derby, scoring players must race round a track whilst other players physically block them to stop them; without the use of collisions, this would be a simple athletic race, whereas in roller-derby, the allowing of blocking and collisions makes for a complex and nuanced sport, albeit one with relatively high risks of injury.

Figure 3 shows our collision space re-shaded with respect to the level of adventure involved. When risk and likelihood of collisions are both low, so is the level of adventure. As risk severity becomes higher or likelihood is higher, adventure is higher. If we look at sports as an examplar of collision based entertainments, we can see that collision based excitement can be generated both by high likelihood of collision, such as in martial arts or boxing, or of taking very high severity risks but which are not likely to happen, such as in roped climbing, where safety equipment is used to reduce the risk of falls, but in the event of a fall, the ensuing collision is likely to severely injure or kill a climber. As we increase both risk severity and likelihood, we get into the realms of extreme sports and increased adventure. However, as shown in the figure, there is clearly a limit to this adventure; as collision becomes more and more certain, and risk severity gets greater, at some point we cross the line between extreme sport and deliberate suicide, something which we would argue is no longer adventure. Where we place that boundary is very much a grey area - for example there is some controversy relating to the extreme sport of 'wingsuit' flying, where the fatality rate of the activity is so high that sustained engagement with the sport almost inevitably ends in death.

3.2 The Matrix of Empowerment

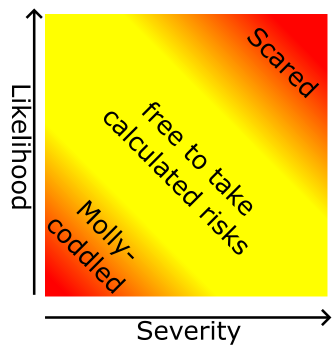

Figure 4: Looking at collisions in terms of empowerment, reducing risk of collision excessively can 'mollycoddle' people, removing their freedom to act as they wish in the world; this can be seen in attempts to reduce risk in childhood play by restricting the activities of children. Creating severe and high likelihood risks can also reduce freedom, for example if a wide road is placed in a neighbourhood, it encourages fast driving, which restricts the ability of those living in the neighbourhood to walk or play in the vicinity of the road. Allowing calculated risks of low-severity or low likelihood collisions may empower people by giving them more freedom to act as they wish.

The freedom to collide can be considered a matter of somatic freedom – a freedom to learn about our bodies, express ourselves somatically, and to act freely within the world. This is not an argument for unlimited freedom as there are boundaries to what is morally right within the context of both society and design practice. However, removing the possibility of collision can encroach upon our somatic freedoms. For example, playful colliding, especially that done by children, is an aspect part of their right to learn and grow in the world [16]. Although children should be protected from situations where they are at risk of becoming seriously hurt, removing the possibility for them to collide is ultimately a restriction on their right to play. Play can be seen as a child's freedom and a fundamental part of their development [18]. In fact, adults should also have the right to play – not matter whether rich or poor [16]. Previous HCI research has also recognised that many people exercise their right to deliberately engage in uncomfortable or even dangerous experiences, such watching scary films, participating in provocative performances and installations, riding roller-coasters and participating in extreme sports, inspiring the design strategy of 'uncomfortable interactions' [6].

In this reframing, we argue that unthinking design to avoid collisions can *disempower* people. As an example we can see the effect of design focused on motor car use in the 20th century; as road building progressed, major roads drove barriers through cities, while residential roads lost their valuable function as playgrounds. This has had a particular impact on children: Björklid [7] discusses how concerns of parents and other authority figures for road safety restricted children's opportunities to play outdoors, a finding echoed by Aziz and Said [5] who report how increased traffic hinders access to parks and open spaces and residential streets become barriers to, rather than resources for, play. More progressive 21st century approaches to management of city traffic have instead focused on limiting speeds to those where pedestrians are safe in the event of a collision, and encouraging driver behaviour that acknowledges that cities are 'shared spaces' where no one has right of way [19]. Such approaches whilst they potentially increase risk of collisions, lower the impact of such collisions, and dramatically reduce the restrictions placed on pedestrian movement in the city.

If we look at this in terms of our collision design space, we can see that by restricting our designs to those which encourage zero collision, we can disempower people, as seen in segregated designs of urban space in the 20th century, or in actions to restrict children from undertaking dangerous play. However design which increases risk of severe collision may also create de-facto restrictions on human freedom, as seen for example with the design of fast, wide roads in cities, which whilst they may in theory be open to pedestrian and cycle traffic, may in practice encourage driving behaviour such that only the foolhardy would walk or cycle on the roadway. As such, we see strong arguments for design which accepts that low-impact collisions between users and systems may be inevitable, and rather than segregating the two or restricting behaviours excessively, instead aims to keep such collisions safe, maintaining people's freedom to move and empowering them to act as they wish even whilst sharing space with our technological designs.

3.3 The Matrices of Consent (or not)

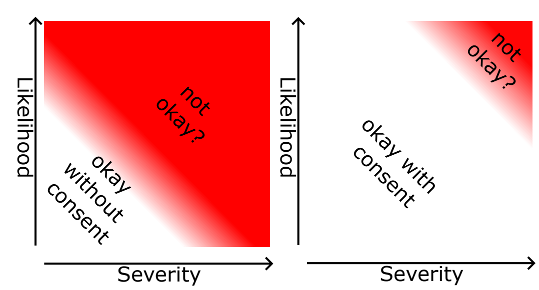

Figure 5: Without some kind of explicit or implicit consent, it is hard to justify designs which make use of more extreme levels of collision. When users are consenting to collisions, we may be able to apply a far greater level of collisions. However even with consent there will be limits in both what is morally right, and what is legally permissible. For example in many jurisdictions it is not legal to build machines to assist with suicide [52]. There may be areas in which designing deliberately for extreme collisions outside the boundaries of consent are appropriate, such as in the military or law enforcement. Whilst HCI work clearly goes on these areas (e.g. [25]), the morality of working to create military systems is way beyond the scope of this paper or the authors' expertise.

In a risk matrix, one key element which is largely absent is what risks people do and don't consent to in a given situation. Where collisions are concerned this is clearly a key driver of our design choices. As a basic example, we can consider punching a person in the face. In general life, this is largely frowned upon, and we can assume that people do not consent to face punching. However, if a person is taking part in a boxing match, whilst they may not *want* their face punching, in the event that it does happen, we can assume some level of consent for the possibility of a face-hand collision. Going beyond boxing, where someone is explicitly taking a risk of a face punch, there is actually a further situation, where someone asks another person to punch them in the face, and does not defend themselves. At this point, the situation becomes both ethically more complex, and as designers we have to ask ourselves the question of whether it is okay for people to deliberately consent to harmful collisions, and if so what level of harm is acceptable. When addressing such questions, we may also need to be aware of the legal status of such activities in the jurisdictions we wish to work in; for example in the UK, whilst there is a well established legal right to undergo painful and risky procedures such as body-piercing, there is also an established case-law that places limits on the possibility to consent to extreme pain for pleasure alone - for example in UK House of Lords Judgement R v Brown 1993 [22], it was ruled that certain types of sadomasochistic sexual activity could not be justified by the consent of participants, with one judge stating that:

> "Society is entitled and bound to protect itself against a cult of violence. Pleasure derived from the infliction of pain is an evil thing. Cruelty is uncivilised." [22]

.

Because of the effect of consent on collision situations, a single reframing of our collision-space is not sufficient here. Instead we will consider three levels of consent and how each affects what aspects of our collision-space are appropriate for design. Firstly, we must consider situations where people do not consent to a collision; in this case, we may primarily focus our design towards the low-risk of collision, and prioritise avoiding collisions where reasonably possible (Fig 5-left). Then we have the situation analogous to boxing, or extreme sports with a risk of falling or crashing, where people are choosing to undertake an activity which involves a risk of collision (Fig 5-right); in these situations we may wish as designers to support people in exposing themselves to low risks of extreme collisions (e.g. mountain climbing), or to highly likely but lower consequence collisions as may be seen in sports such as roller derby or rugby. As designers, we have to make personal decisions as to what kind of collision risk taking we are willing to support, i.e. what potential level of consequences we are happy to work with, and how likely they are to occur; there is almost certainly a cut-off, but even within the authors of this paper we have a wide range of views as to where it should be placed. At the extremes of the space, we have situations where someone is in practice deliberately exposing themselves to dangerous collisions - be it jumping off high things or engaging with systems in a way which is deliberately designed to cause themselves pain. Here we are entering a space which is ethically challenging to design in, and as described above might not be considered appropriate even with consent. At the most extreme we enter the world of 'suicide machines', technology to hasten the death of users, which in reality have been deployed in situations of terminal illness [52], but have also been postulated (and purportedly built) as an entertainment device in the form of a VR headset in which when a player dies in a game, the headset releases explosions which kill them in reality [38].

Whilst as authors we are very much unqualified to design in such spaces and do not wish to do so, we do recognise the existence of situations whose morality perhaps cannot be described by consent alone - in particular, authors in HCI continue to work on technological warfare systems such as unmanned aerial vehicles [26] which may by design aim to involve people in high-risk collisions; similarly, technology may be used in law enforcement situations to induce high-risk collisions with unconsenting suspects. In such situations, consent becomes less of a useful concept.

4 DESIGN IMPLICATIONS

In the previous section, we demonstrated that by reframing collision with respect to values other than avoidance of physical risk, there is clear experiental value to be had from deliberately designing with collisions of various types. In this section we consider what these reframings mean for designers by dividing our likelihood/severity space into four rough areas (Figure 6), and discussing the risks and opportunities presented by each area of the space.

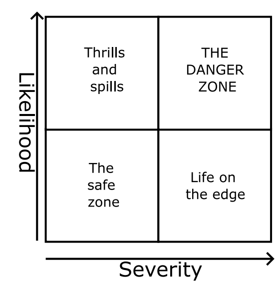

Figure 6: Each of the four quadrants of our collision space support different aspects of user experience.

4.1 The Safe Zone

The bottom left of the diagram in Figure 6 is where most current HCI work lives. Making sure risk of collision is extremely unlikely, and any collisions that users are exposed to are minimal allows for user safety. This approach also reduces liability risks for system designers. However, as discussed above, attempts to constrain people and systems to behave in entirely safe ways may be restrictive of people's freedom. For example if robots are working in the same place as people, it is inevitable that there is some chance of collision; if we restrict the situation so that we cannot come close to robots, we miss many of the opportunities provided by 'collaborative robots' which may physically interact with humans [56]. We consign telepresence robots to potentially becoming trapped in spaces where a real human might gently barge through a crowd - disadvantaging the operator from socially acceptable behaviours exhibited between humans [48]. If we argue that electric cars must be segregated entirely from pedestrians, we make the same mistakes that well meaning traffic designers made in the 20th Century [19]. Finally, it is clear that this area represents designs which while they are extremely physically safe, may lack the excitement of riskier areas of our collision space - as an analogy, this space is the equivalent of cycling slowly along an entirely flat trail; it can offer enjoyment, but will never reach the excitement levels of riding fast down a rocky mountain.

4.2 Thrills and Spills

The top left of the diagram is for us a really interesting area for design. As consequences are relatively minor, experiences in this area offer the thrill of imparting, receiving or watching collisions, but without significant long-term risk. It is also generally acknowledged that people can consent to this kind of design in the form of contact sports or martial arts. This area offers potential for a wide range of new and exciting HCI experiences and to design systems which do not require human activity to be constrained to maintain perceived standards of perfect safety. There has been a long running thread in HCI of building sports-like experiences such as Exertion Games [44] though many of these shy away from direct actor-actor collision. We assert that such collisions are entirely viable as a design space as evidenced by examples like [41]. On the negative side, activities such as contact sports are not playable by all people, and impact of collisions may vary strongly depending on bodily differences such as strength, size and balance. Use of even minor collisions whilst fun, carries the potential to make our experiences less accessible. Interestingly however, we should not assume that reasons of accessibility and bodily difference mean we should entirely avoid this space, we should instead be aware that people with different bodies may experience these kind of collisions in ways that require modified approaches to design; i.e. rather than just assume people who use wheelchairs never want to crash, we should consider how they can take part in enjoyable activities involving frequent collisions (as an example of mechanical and human design in this space, see the crash only highlights video from the Vancouver Wheelchair Rugby competition [3])

4.3 Life on the Edge

At the bottom right of our diagram, we have designs with potentially serious consequences, but where collisions are low likelihood. Experiences in this area have a similar risk profile to motorsports, mountaineering and rock climbing; they are things where the vast majority of the time, you will cheat death, but the potential is always there. This kind of activity gives us the thrill of near-misses and skillfully avoiding injury, and is often highly exciting for spectators. As authors we partake in various outdoor sports that fit this description, including mountain unicycling, rock climbing, ice swimming and horse-riding, all of which are activities which are generally unlikely to end badly, but in the case of a failure can end in life-changing consequences or even death. Typically these pursuits involves some kind of expertise - for example, one doesn't simply unicycle down a mountain without first being very good at unicycling. Consent is more of a grey area in such activities; consent can only really be meaningful if it is entirely clear to participants what risk they are taking on; as such making risk level clear to participants is important; as an example in mountain bike trail design, a 'qualifier' section is often used before high-consequence sections. A qualifier requires a high level of skill, but is deliberately low-consequence, meaning that only those who have the skill to pass it can continue to the main trail section which has more potential for serious crashes [4].

4.4 The DANGER ZONE

When designs have high likelihood of collisions which may have serious consequences, we are into the highly ethically complex area for design which we label 'the danger zone' (top right of Figure 6. As researchers, none of the authors work in this area at all. At its least severe, this part of the design space includes high-risk, high-thrill activities such as extreme sports. Sky-diving is an example of an extreme sport which has been addressed in HCI by multiple authors [11, 15, 57]; interestingly however, whilst authors build systems which have potential to train people in real skydiving, all HCI research we found in this area works entirely in safe simulation environments. At the top-right extreme of the design space, we have situations where collision is designed to be extremely likely or inevitable; collision based systems which fall into this area include highly morally problematic designs such as killer robots, suicide machines and sports which are so extreme that they are likely to kill participants (e.g. 'free-climbing' without safety equipment, wing-suiting, base-jumping, free-diving). Building HCI systems which actually create high risk of severe collisions is in many ways hard to justify ethically. Consent only gets us so far in justifying such systems, and we have to move into complex areas of ethics such as ethics of warfare, suicide, and consider what type of collision risk it is acceptable to encourage people to take.

5 CONCLUSIONS

As computer based technology increasingly shares and manifests itself in the same space as humans, such as in the form of assistive robots or drones or other systems with physical embodiments, it is vital that we design with the acceptance of a level of collisions. As we showed above, aiming for complete collision avoidance places excessive restrictions on human activity, meaning that systems which expose people to a controlled level of collision risk have greater potential to empower people and give them bodily autonomy in return for a controlled risk of collision.

By mapping collision potential on a design space based on two axes of collision severity and likelihood, we can see that there is a rich and relatively unexplored design space of collision experiences. The design area of frequent, severe collisions ('THE DANGER ZONE') delineates a range of extreme experiences which are highly ethically complex, and may not even be possible for people to reasonably consent to undergoing; we believe unless one is willing to engage seriously with matters such as ethics of war, assisted suicide and the rights and wrongs of extreme risk taking, exploring frequent-severe collision based design is hard to justify. However we believe that the space of minor but frequent collisions has much potential for as yet undiscovered creativity and are focusing significant design effort into understanding the nature of such experience in the future; we are also interested in the area of computer supported outdoor sports which pose severe but low-likelihood collision risks; design in this area is exciting in its potential to create highly thrilling experiences, although we require more research and exploration to fully understand the ethics of building and deploying such designs.

ACKNOWLEDGMENTS

This work was supported in part by: Marianne and Marcus Wallenberg Foundation project (MMW 2019.0228) and Swedish Research Council (project 2021-04659).

REFERENCES

[1] Laurent Aguerreche, Thierry Duval, and Anatole Lécuyer. 2010. Reconfigurable Tangible Devices for 3D Virtual Object Manipulation by Single or Multiple Users. In *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology* (Hong Kong) *(VRST '10)*. Association for Computing Machinery, New York, NY, USA, 227–230. https://doi.org/10.1145/1889863.1889913
[2] Louis Anthony (Tony) Cox Jr. 2008. What's wrong with risk matrices? *Risk Analysis: An International Journal* 28, 2 (2008), 497–512.
[3] Canadian Wheelchair Sports Association. 2011. Wheelchair Rugby Hard Hits - Vancouver Invitational. https://www.youtube.com/watch?v=tZ0zCgCgswA Accessed: 2022-12-15.
[4] International Mountain Bicycling Association. 2018. *Guidelines for a Quality Trail Experience.*
[5] Nor Fadzila Aziz and Ismail Said. 2012. The trends and influential factors of children's use of outdoor environments: A review. *Procedia-social and behavioral sciences* 38 (2012), 204–212.
[6] Steve Benford, Chris Greenhalgh, Gabriella Giannachi, Brendan Walker, Joe Marshall, and Tom Rodden. 2012. Uncomfortable interactions. In *Proceedings of the sigchi conference on human factors in computing systems*. 2005–2014.
[7] Pia Björklid. 1994. Children-traffic-environment. *Architecture and Behaviour* 10, 4 (1994), 399–406.
[8] Michael S Brady. 2019. Suffering in sport: why people willingly embrace negative emotional experiences. *Journal of the Philosophy of Sport* 46, 2 (2019), 115–128.
[9] Barry Brown and Eric Laurier. 2017. The trouble with autopilots: Assisted and autonomous driving on the social road. In *Proceedings of the 2017 CHI conference on human factors in computing systems*. 416–429.
[10] Mariana Brussoni, Lise L Olsen, Ian Pike, and David A Sleet. 2012. Risky play and children's safety: balancing priorities for optimal child development. *International journal of environmental research and public health* 9, 9 (2012), 3134–3148.
[11] Anna Clarke and Per-Olof Gutman. 2023. An automatic control system with human-in-the-loop for training skydiving maneuvers: Proof-of-concept experiment. *International Journal of Human-Computer Studies* 170 (2023), 102960.
[12] Daniel Delgado Bellamy, Gregory Chance, Praminda Caleb-Solly, and Sanja Dogramadzi. 2021. Safety Assessment Review of a Dressing Assistance Robot. *Frontiers in Robotics and AI* 8 (2021). https://doi.org/10.3389/frobt.2021.667316
[13] Nijs Jan Duijm. 2015. Recommendations on the use and design of risk matrices. *Safety science* 76 (2015), 21–31.
[14] Nat Durlach and Mel Slater. 2000. Presence in Shared Virtual Environments and Virtual Togetherness. *Presence: Teleoperators and Virtual Environments* 9, 2 (04 2000), 214–217. https://doi.org/10.1162/105474600566736 arXiv:https://direct.mit.edu/pvar/article-pdf/9/2/214/1623414/105474600566736.pdf
[15] Horst Eidenberger and Annette Mossel. 2015. Indoor skydiving in immersive virtual reality with embedded storytelling. In *Proceedings of the 21st acm symposium on virtual reality software and technology*. 9–12.
[16] Pedro Ferreira. 2015. *Play as freedom: Implications for ICT4D.* Ph. D. Dissertation. KTH Royal Institute of Technology.
[17] Paul R Garvey and Zachary F Lansdowne. 1998. Risk matrix: an approach for identifying, assessing, and ranking program risks. *Air Force Journal of Logistics* 22, 1 (1998), 18–21.
[18] Peter Gray. 2013. *Free to learn: Why unleashing the instinct to play will make our children happier, more self-reliant, and better students for life.* Basic Books.
[19] Ben Hamilton-Baillie. 2008. Shared space: Reconciling people, places and traffic. *Built environment* 34, 2 (2008), 161–181.
[20] Ellen Beate Hansen Sandseter. 2007. Categorising risky play-how can we identify risk-taking in children's play? *European early childhood education research journal* 15, 2 (2007), 237–252.
[21] Dirk Helbing and Peter Molnar. 1995. Social force model for pedestrian dynamics. *Physical review E* 51, 5 (1995), 4282.
[22] UK House of Lords. 1993. Brown/Lucas/Jaggard/Laskey/Carter v Regina. https://www.bailii.org/uk/cases/UKHL/1993/19.html
[23] Shaoyan Huang, Huidong Bai, V B H Mandalika, and Robert W. Lindeman. 2018. Improving Virtual Reality Safety Precautions with Depth Sensing. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction* (Melbourne, Australia) *(OzCHI '18)*. Association for Computing Machinery, New York, NY, USA, 528–531. https://doi.org/10.1145/3292147.3292241
[24] ISO 14971 2019. *Medical devices — Application of risk management to medical devices.* Standard. International Organization for Standardization, Geneva, CH.
[25] Liang Jie, Cao Jian, and Wang Lei. 2017. Design of multi-mode UAV human-computer interaction system. In *2017 IEEE International Conference on Unmanned Systems (ICUS)*. 353–357. https://doi.org/10.1109/ICUS.2017.8278368
[26] Liang Jie, Cao Jian, and Wang Lei. 2017. Design of multi-mode UAV human-computer interaction system. In *2017 IEEE international conference on unmanned systems (ICUS)*. IEEE, 353–357.
[27] Jon Kabat-Zinn, Leslie Lipworth, and Robert Burney. 1985. The clinical use of mindfulness meditation for the self-regulation of chronic pain. *Journal of Behavioral Medicine* 8, 2 (June 1985), 163–190. https://doi.org/10.1007/bf00845519
[28] Sandra Kamping, Jamila Andoh, Isabelle C. Bomba, Martin Diers, Eugen Diesch, and Herta Flor. 2016. Contextual modulation of pain in masochists. *Pain* 157, 2 (Feb. 2016), 445–455. https://doi.org/10.1097/j.pain.0000000000000390
[29] Linda A Keeler. 2007. The Differences in Sport Aggression, Life Aggression, and Life Assertion Among Adult Male and Female Collision, Contact, and Non-Contact Sport Athletes. *Journal of Sport Behavior* 30, 1 (2007).
[30] Mingyu Kim, Changyu Jeon, and Jinmo Kim. 2017. A Study on Immersion and Presence of a Portable Hand Haptic System for Immersive Virtual Reality. *Sensors* 17, 5 (2017). https://doi.org/10.3390/s17051141
[31] Hasan Kivrak, Furkan Cakmak, Hatice Kose, and Sirma Yavuz. 2021. Social navigation framework for assistive robots in human inhabited unknown environments. *Engineering Science and Technology, an International Journal* 24, 2 (2021), 284–298.
[32] Kathryn R. Klement, Brad J. Sagarin, and Ellen M. Lee. 2016. Participating in a Culture of Consent May Be Associated With Lower Rape-Supportive Beliefs. *The Journal of Sex Research* 54, 1 (April 2016), 130–134. https://doi.org/10.1080/00224499.2016.1168353
[33] Luv Kohli, Eric Burns, Dorian Miller, and Henry Fuchs. 2005. Combining Passive Haptics with Redirected Walking. In *Proceedings of the 2005 International Conference on Augmented Tele-Existence* (Christchurch, New Zealand) *(ICAT '05)*. Association for Computing Machinery, New York, NY, USA, 253–254. https://doi.org/10.1145/1152399.1152451
[34] Thibault Kruse, Amit Kumar Pandey, Rachid Alami, and Alexandra Kirsch. 2013. Human-aware robot navigation: A survey. *Robotics and Autonomous Systems* 61, 12 (2013), 1726–1743.
[35] Przemyslaw A Lasota, Terrence Fong, Julie A Shah, et al. 2017. A survey of methods for safe human-robot interaction. *Foundations and Trends® in Robotics* 5, 4 (2017), 261–349.
[36] Siri Leknes and Irene Tracey. 2008. A common neurobiology for pain and pleasure. *Nature Reviews Neuroscience* 9, 4 (April 2008), 314–320.
[37] Pedro Lopes, Alexandra Ion, and Patrick Baudisch. 2015. Impacto: Simulating physical impact by combining tactile stimulation with electrical muscle stimulation. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*. 11–19.
[38] Palmer Luckey. 2022. If you die in the game, you die in real life. https://palmerluckey.com/if-you-die-in-the-game-you-die-in-real-life/
[39] Ride Magazine. 2016. Worst Skateboarding Slams Compilation. https://www.youtube.com/watch?v=-wqwaIh2tYE Accessed: 2022-12-15.
[40] Ibrahim Mahamid. 2011. Risk matrix for factors affecting time delay in road construction projects: owners' perspective. *Engineering, Construction and Architectural Management* (2011).
[41] Joe Marshall, Conor Linehan, and Adrian Hazzard. 2016. Designing brutal multiplayer video games. In *Proceedings of the 2016 chi conference on human factors in computing systems*. 2669–2680.
[42] Jeremy A. Marvel, Joe Falco, and Ilari Marstio. 2015. Characterizing Task-Based Human–Robot Collaboration Safety in Manufacturing. *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 45, 2 (2015), 260–275. https://doi.org/10.1109/TSMC.2014.2337275
[43] Pamela J. Meredith, Jenny Strong, and Judith A. Feeney. 2006. The relationship of adult attachment to emotion, catastrophizing, control, threshold and tolerance, in experimentally-induced pain. *Pain* 120, 1-2 (Jan. 2006), 44–52. https://doi.org/10.1016/j.pain.2005.10.008
[44] Florian Mueller, Rohit Ashok Khot, Kathrin Gerling, and Regan Mandryk. 2016. Exertion Games. *Foundations and Trends® in Human–Computer Interaction* 10, 1 (2016), 1–86. https://doi.org/10.1561/1100000041
[45] Uchenna Emeoha Ogenyi, Jinguo Liu, Chenguang Yang, Zhaojie Ju, and Honghai Liu. 2019. Physical human–robot collaboration: Robotic systems, learning methods, collaborative strategies, sensors, and actuators. *IEEE transactions on cybernetics* 51, 4 (2019), 1888–1901.
[46] Oxford English Dictionary. 2022. "collision, n.". In *OED Online*. Oxford University Press. http://www.oed.com/view/Entry/36388
[47] Anthony D Pellegrini and Peter K Smith. 1998. Physical activity play: The nature and function of a neglected aspect of play. *Child development* 69, 3 (1998), 577–598.

[48] Irene Rae and Carman Neustaedter. 2017. Robotic Telepresence at Scale. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 313–324. https://doi.org/10.1145/3025453.3025855

[49] Jorge Rios-Martinez, Anne Spalanzani, and Christian Laugier. 2015. From proxemics theory to socially-aware navigation: A survey. *International Journal of Social Robotics* 7, 2 (2015), 137–153.

[50] Steve Roud. 2010. *The lore of the playground: One hundred years of children's games, rhymes and traditions*. Random House.

[51] Maria V Sanchez-Vives and Mel Slater. 2005. From presence to consciousness through virtual reality. *Nature Reviews Neuroscience* 6, 4 (2005), 332–339.

[52] Tracy Schroepfer. 2015. The journey to understanding the wish to hasten death. In *The Patient's Wish to Die: Research, Ethics, and Palliative Care*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198713982.003.0006

[53] Steven Silva Mendoza, Dennys Paillacho, Nervo Verdezoto Dias, and Juan Hernandez Vega. 2022. Towards online socially acceptable robot navigation. (2022).

[54] Paul Tennent, Sarah Martindale, Steve Benford, Dimitrios Darzentas, Pat Brundell, and Mat Collishaw. 2020. Thresholds: Embedding Virtual Reality in the Museum. *J. Comput. Cult. Herit.* 13, 2, Article 12 (may 2020), 35 pages. https://doi.org/10.1145/3369394

[55] Philip Thomas, Reidar B Bratvold, Eric Bickel, et al. 2014. The risk of using risk matrices. *SPE Economics & Management* 6, 02 (2014), 56–66.

[56] Federico Vicentini. 2021. Collaborative robotics: a survey. *Journal of Mechanical Design* 143, 4 (2021).

[57] Yulie Wang and Boku Li. 2021. Research on skydiving experience design under virtual reality technology. In *International Conference on Image Processing and Intelligent Control (IPIC 2021)*, Vol. 11928. SPIE, 248–251.