Virtual Reality as a new approach for risk taking assessment

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10 **Abstract**

11 Understanding how people behave when facing hazardous situations, how intrinsic and extrinsic
12 factors influence the risk taking (RT) decision making process and to what extent it is possible to
13 modify their reactions externally, are questions that have long interested academics and society in
14 general. In the spheres, among others, of Occupational Safety and Health (OSH), the military, finance
15 and sociology, this topic has multidisciplinary implications because we all constantly face risk taking
16 situations. Researchers have hitherto assessed risk taking profiles by conducting questionnaires prior
17 to and after the presentation of stimuli; however, this can lead to the production of biased, non-
18 realistic, risk taking profiles. This is due to the reflexive nature of choosing an answer in a
19 questionnaire, which is remote from the reactive, emotional and impulsive decision making processes
20 inherent to real, risky situations. One way to address this question is to exploit VR capabilities to
21 generate immersive environments that recreate realistic seeming but simulated hazardous situations.
22 We propose VR as the next-generation tool to study risk taking processes, taking advantage of the
23 big four families of metrics which can provide objective assessment methods with high ecological
24 validity: the real-world risks approach (high presence VR environments triggering real-world
25 reactions), embodied interactions (more natural interactions eliciting more natural behaviours),
26 stealth assessment (unnoticed real-time assessments offering efficient behavioural metrics) and
27 physiological real-time measurement (physiological signals avoiding subjective bias). Additionally,
28 VR can provide an invaluable tool, after the assessment phase, to train in skills related to risk taking
29 due to its transferability to real-world situations.

1   Introduction

31 Each year, deficient Occupational Safety and Health (OSH) practices cause a global cost of
32 approximately 2680 billion euros (Elsler et al., 2017). Although OSH training has shown positive
33 impacts in the workplace, its effectiveness is below expectations (Robson et al., 2012). It has been
34 demonstrated that the natural differences between individuals can appreciably influence this low
35 effectiveness at several levels, cognitive, motivational and functional, among others (Motowildo et
36 al., 1997). Risk propensity, defined as the "willingness to take risks" (MacCrimmon and Wehrung,
37 1990) and risk perception, defined as the individual´s assessment of how risky a situation is (Baird
38 and Thomas, 1985), have been shown to have strong influence on risky decision making behaviours

39   (Sitkin and Weingart, 1995). The measurement of risk taking (RT) attitudes is a recognised challenge
40   for researchers and practitioners. Researchers have mostly employed self-report instruments to assess
41   individual constructs based on theoretical psychological models (Brockhaus Sr., 1980; Ford et al.,
42   1990; Gullone et al., 2000; Portell and Solé, 2001; Steinberg, 2004; Gardner and Steinberg, 2005;
43   Sneddon et al., 2013; Rodríguez-Garzón et al., 2015;). We have not found any one model that
44   defines RT, thus its measurement requires further investigation. Lejuez et al. (2002) developed and
45   validated a laboratory-based behavioural measure of risk taking (Balloon Analogue Risk Task –
46   BART). While this is a validated tool that has been used in several studies, we believe that it is
47   desirable to develop a more ecological system to measure risk taking. VR provides the capability of
48   creating interactive environments in which users can perform while their behavioural responses are
49   recorded (Parsons, 2015). Accordingly, we propose that virtual environment based assessments are
50   tools that can enhance the ecological validity of the evaluation of the responses evoked (Parsey and
51   Schmitter-Edgecombe, 2013).

52   In this article we focus on the measurement of risk taking using physiological and behavioural
53   metrics, with VR being employed as a tool to create immersive situations. We propose to use VR to
54   assess risk taking attitudes under the paradigm of stealth assessment. VR can provide engaging
55   virtual worlds which will allow real time measurement of RT behaviours.

56   This paper is comprised of four sections. In the first we review the theoretical framework of risk
57   taking in the previous literature. In the second we summarize the extant instruments for the
58   measurement of risk taking behaviours and discuss the current issues that make us believe that there
59   is a need to establish a new approach. In the third we propose VR as a step forward in the assessment
60   of risk taking. The fourth section briefly discusses the substantial implications raised by the article
61   and our proposals for future research in this field.

62   **2   Research into risk taking**

63   Risk taking research can be said to have started with the nuclear debate of the sixties. It was focused
64   on risk acceptance and dealt with factors such as benefits and voluntariness. Since then, several more
65   factors have been proposed for the explanation of risk taking: trust, trustworthiness and trust
66   propensity (Colquit et al., 2007); supportive supervision, job autonomy and communication quality
67   (Parker et al., 2001); problem framing and outcome history (Sitkin and Weingart, 1995); expected
68   utility (Kahneman and Tversky, 1986); genre (Byrnes et al., 1999) and boredom (Schroeter et al.,
69   2014).

70   While these factors have been demonstrated to influence risk taking, individual differences constitute
71   a key element in decision making processes (see Figure 1). According to Rundmo, 1996, a biased
72   perception of risk – understood as the subjective evaluation of a risk - can lead to misjudgements of
73   potentially hazardous risk sources. Therefore, if the subjective evaluation of a risk differs from the
74   objective risk, this should be corrected (Risk Research Committee, 1980). Personality traits influence
75   attitude towards risk, prompting risk seeking or risk aversion behaviours. This set of personal, innate,
76   basic characteristics associated with risk were named Intrinsic Risk Attitude (IRA) by Schoemaker
77   (1993) and have been shown to be consistent in various situations and contexts (Dohmen et al.,
78   2011). Additionally, cognitive and affective states are also considered to be key influencers in the
79   decision making process. We highlight mood and cognitive load as two main representative factors in
80   this category. Mood has a strong influence on risk taking. People in a positive mood tend to focus on
81   the benefits of a risky situation, much more so than those in neutral mood, making them more
82   susceptible to undertake risky behaviours (Yuen and Lee, 2003; Forgas, 1982, 1995; Forgas and

83 Bower, 1987). On the other hand, people in a negative mood overestimate risks and try to avoid
84 potential loss and, therefore, think and act more carefully (Jorgensen, 1996). Cognitive load, the
85 amount of mental activity involved in working memory, might also play a role in risk perception,
86 since some kind of decisions, based on utilitarian judgments, require additional cognitive resources
87 (Greene et al., 2008).

88

89   Figure 1 here

90

91 3   Risk taking measures. Current issues

92 RT measurement is a non-deterministic and non-standardized process based on different
93 perspectives. Traditionally, most theories of human behaviour are based on a model of the human
94 mind that assumes that humans can think and verbalize accurately about their attitudes, emotions and
95 behaviours (Brief, 1998; Simon, 1976). To date, most of the theoretical constructs used in RT
96 assessment are based on explicit measures such as self-reports. However, recent advances in
97 neuroscience have demonstrated that most of the brain processes that regulate our emotions, attitudes
98 and behaviours are not conscious. That is, they are implicit processes that, in contrast to explicit
99 processes, humans cannot verbalize (Barsade et al., 2009; Becker et al., 2011; George, 2009).

100 Several explicit measures of RT, oriented to evaluate attitude to risk, deferred risk perception or
101 expected risk behaviour, have been proposed in the last fifty years. Some authors have employed
102 self-report measures based on questionnaires on compliance with safety practices in the workplace
103 (Parker et al., 2001; Mohamed et al., 2009; Seo et al., 2015), attitude towards risk and organizational
104 commitment (Kivimäki and Kalimo, 1993) and in studies into decision making (Sitkin and Weingart,
105 1995). On the other hand, some works have drawn on theoretical multidimensional models based on
106 psychological constructs, such as personality (Lejuez et al., 2002; Skeel et al., 2007), impulsivity
107 (Lejuez et al., 2002), sensation seeking (Horvath and Zuckerman, 1993; Lejuez et al., 2002) and
108 situational awareness (Lejuez et al., 2002).

109 However, as in many other disciplines, pre- and post-experiment questionnaires have an important
110 intrinsic bias since individuals' cognitive and psychological states will be different when they answer
111 the questionnaires to when they actually underwent the experiences that the researchers wish to
112 analyse (Kivikangas et al., 2011). As stated in (Wang et al., 2015), this tendency is primarily due to
113 "social desirability effects", which can lead to untrue accounts of behaviour, attitudes and beliefs
114 (Paulhus, 1991). In addition, there may be different interpretations of specific self-report items,
115 resulting in unreliability and poorer validity (Lanyon and Goodstein, 1997). Lastly, some self-
116 reporting questions need people to possess overt knowledge of their dispositions (Schmitt, 1994) and
117 this does not always run true.

118 To our knowledge, the BART (Lejuez et al., 2002) constitutes, to date, the only tool for RT
119 measurement using implicit measures. The authors developed and validated a laboratory-based
120 behavioural measure of risky behaviours. In this task, a balloon was presented in the middle of the
121 screen. Subjects were asked to pump it as much as possible, knowing that it could exploit at any time.
122 Participants were told that they would obtain a financial reward the more they could inflate the
123 balloon without breaking it. Although the reliability of this tool has been retested (White and Lejuez,
124 2008), extensive investigations have demonstrated that the correspondence between performance in

125 neuropsychological tests and real-life behaviours is very weak (Manchester et al., 2004; Sbordone,
126 2008; Bottari et al., 2009).

127 In the BART validation study, researchers employed measures of impulsivity, sensation seeking and
128 behavioural constraint. We consider this a good basis to build on, since each of these constructs has
129 been investigated independently and associated with risk taking. Firstly, impulsivity has been
130 associated with risk taking in terms of drug use, drink driving and seatbelt use (de Wit, 2009;
131 Stanford et al., 1996). Some authors have also demonstrated its connection with emotional self-
132 control, inhibition and, especially, the management of frustrating situations (Cooper et al., 2000;
133 Boyer, 2006). In addition, researchers have studied the relationship between the sensation seeking
134 trait and risk taking in several domains, such as recreation, health, career, finance, safety and social
135 life (Nicholson et al., 2005). Donohew et al. (1999) concluded that sensation seeking is an important
136 factor in sexual risk taking. According to Tellegen´s model (1985), behavioural constraint is one of
137 the dimensions that composes personality. The behavioural constraint factor encompasses control,
138 harm avoidance and traditionalism facets. In the same way, there is empirical evidence of the
139 influence of personality traits on risk taking attitudes, in particular punishment avoidance (Paulus et
140 al.,2003). We can find an interesting study from Wills et al. (2006) supporting this idea in the
141 substance abuse field.

142 **4   Limitations of current risk taking measures**

143 As mentioned previously, to date the majority of RT assessment tools has been based on explicit
144 measures and the use of questionnaires.

145 BART, with its multi-dimensional set of psycho-cognitive influences, represents the only alternative
146 to explicit measures of RT behaviour, but its design has some intrinsic limitations that current
147 technologies could help to overcome.

148 In this regard, we believe that the existing measurement instruments do not reflect real situations, in
149 which the subjects can perform as in real life, which leads to skewed results. In the laboratory the
150 controlled stimuli given to subjects often do not include variables that are present in real life
151 situations. Thus, the ecological validity of these methodologies, such as BART, is quite limited.
152 Furthermore, these measurement tools do not involve any strong physical interaction, but require
153 only simple actions, such as clicking a mouse, ignoring the influence of the reactions of the rest of
154 the body. In addition, when an individual is submitted to the currently available tests, (s)he is aware
155 that (s)he is being assessed and can alter the outcomes; so we propose stealth assessment as a means
156 of obtaining reliable results about real behaviours unnoticed by the subject. Lastly, we suggest that
157 physiological processes must be considered as important measures of risk taking, as these
158 measurements are uncontaminated by the participant's answering style, social desirability,
159 interpretations of questionnaire item wording, the limits of his or her memory or by observer bias
160 (Kivikangas et al., 2011). Thus, we propose an alternative measurement method which aims to
161 advance in four specific aspects:

162   1) **Real-world risks**: As stated in Bornovalova et al., 2009, p.261. "[BART] … did not collect
163   information on "real-world" risk-taking. It would be of both theoretical interest and clinical
164   relevance to examine whether the current results "hold" when considering actual risk-taking
165   behaviour". We want to expose individuals to (almost) real risks in order to obtain (almost)
166   real reactions. Amit et al. (2014) found that humans demonstrate two kinds of thought
167   processes in any given situation, verbal and visual. A person who tends to verbal thinking

168 builds meanings using words. This generates an abstract interpretation of a concept. It is
169 usual, in this circumstance, to exhibit controlled cognitive processes, experience high
170 psychological distance and to make utilitarian judgements. In contrast, visual thinking is
171 associated with the use of images to represent concepts, generating a sense of proximity and
172 the making of deontological judgements. People who tend towards visual thinking are willing
173 to be guided by emotional automatic processes and are strongly influenced by secondary
174 emotions. Using the real-world risks approach, we suggest that we can evoke the sensation of
175 physical risk and initiate visual thinking that would arise in a real life, risky situation.

176 **2) Embodied cognition**: How the actions of our bodies influence our perception,
177 communication and learning processes is a field of study known as Embodied Cognition
178 (EC). EC can be defined by stating that cognition is solidly based on corporal interactions
179 with the physical environment (Gallagher, 2005; Wilson, 2002). Going into more detail,
180 systems for sensing, acting and thinking are intrinsically interdependent and human cognition
181 is made up of complex, specific representations combining all three systems (Soler et al.,
182 2017). During recent years, instructional methods based on bodily interactions have been
183 developed to create meaningful connections between physical activity and different
184 knowledge domains, mainly in the STEM (Science, Technology, Engineering and Maths)
185 area, strongly linked to the new Mixed Reality media (Lindgren and Johnson-Glenberg,
186 2013). To a certain extent, embodied learning could represent an important foundation on
187 which to build a whole set of interactive, immersive learning environments. This concept is
188 supported by previous research (Kontra et al., 2012) that argues that taking a meaningful
189 action enhances learning in comparison to passively perceiving that action. This idea has been
190 strongly supported for decades by classical learning theorists such as Piaget (1952) and
191 Vigotsky (1978). We propose to take advantage of the ideas underlying embodied learning
192 theory and use high level cognitive experiences, involving sensing, acting and thinking, to
193 measure and change attitudes in a deeper, more effective way.

194 **3) Stealth assessment**: "When embedded assessments are seamlessly woven into the fabric of
195 the learning environment so that they are virtually invisible or unnoticed by the learner, this is
196 stealth assessment" (Shute and Spector, 2008, p.2). More specifically, this method offers the
197 possibility of assessing different behaviours related to concrete capabilities, providing indirect
198 evaluations in real time (Mislevy et al., 2003) and reducing test anxiety, while maintaining
199 validity and reliability (Shute et al., 2008). Stealth assessment fits into the framework of
200 evidence-centred design (ECD), which considers three conceptual models that must be
201 present in stimuli design: the competency model, which aims to define the skills that the
202 researcher wishes to assess; the evidence model, that aims to define specific behaviours and
203 their relationships with particular skills and capabilities; and the task model, which is
204 designed to develop specific scenarios and tasks to prompt skills-related behaviours (Shute,
205 2011). Thus, stealth assessment allows the setting of tasks and creation of situations that can
206 elicit particular behaviours connected with the skills and capabilities to be evaluated.

207 **4) Physiological real-time measurement**: Several physiological measures have recently been
208 proposed as implicit measures of human behaviour (Kivikangas et al., 2011). Skin
209 conductance level has been successfully used as a measure of implicit processes such as
210 stress, affective arousal and cognitive processing (Sequeira et al., 2009). Heart variability
211 (HV) has been used for the implicit measurement of complex phenomena, for example
212 cognitive load (Durantin et al., 2014). Eye tracking (ET) is a very interesting measure of
213 subconscious brain processes, showing correlations with information processing in risky
214 decisions (Glöckner and Herbold, 2011) and problem solving (Knoblich et al., 2001). Recent
215 studies, using Functional Near-Infrared Spectroscopy (fNIRS), into decision making under

216   pressure (Tsujii and Watanabe, 2010) and decision making processes in approach-avoidance
217   theories (Ernst et al., 2013), are highly relevant for RT measures.

218   **5   Virtual Reality and risk taking assessment**

219   Virtual Reality is a 3D synthetic environment able to simulate real experiences in which subjects can
220   interact as if they were in the real world (Alcañiz et al., 2003). VR provides greater immersion,
221   fidelity and higher level of active user involvement than traditional methods of assessment and
222   training (Hedberg and Alexander, 1994). In our view, VR constitutes a suitable tool for behavioural
223   measurement, since it complies with the requirements of the four specific aspects discussed in the
224   previous section: (1) the real-world risks approach, (2) embodied learning, (3) stealth assessment and
225   (4) physiological real-time measurement.

226   (1) According to Slater (2009), the result of immersion through technology is the psychological state
227   of "being there", where the subject essentially forgets that (s)he is in a virtual reality setting. This
228   produces a sense of presence and a "plausibility illusion" which evoke the perception that what is
229   happening in the VR is actual and allows subjects to interact and behave as they might in real life.
230   VR is being used increasingly for natural phenomena and social interactions simulation, since it has
231   been demonstrated that neural mechanisms in humans when they are immersed in a virtual
232   environment are similar to those in real life (Alcañiz et al., 2009). When we talk about training and
233   learning, failure is a necessary ingredient. There is evidence that people who have faced real hazards
234   have a more cautious attitude towards OSH (Cavalcanti and Soares, 2012). Hazards in real life can
235   involve serious danger. This is why VR emerges as a potential medium for risk taking assessment
236   and training, allowing users to operate, without risks, in a quasi-real environment (Amokrane et al.,
237   2008). VR allows the exposure of a person to a risky situation and the activation of high fidelity
238   cognitive processes and behaviours due to the plausibility of the immersion. (2) VR environments
239   allow users to take part in an embodied learning experience, mainly through physical interactions
240   (Kilteni and Groten, 2012). Going further with this concept (Dourish, 1999), we consider a virtual
241   interaction to be fully embodied when it is believable, in the sense of using our body coherently as
242   we do in the real world. The dual-process theory of moral judgment, when it refers to moral
243   dilemmas, makes a distinction between personal and impersonal dilemmas (Greene et al., 2001;
244   Greene, 2009): personal dilemmas are conflicts in which the subject experiences the situation in the
245   first person and actions are carried out physically – e.g. pushing. Conversely, impersonal dilemmas
246   are seen from the outside, and the subjects do not take overt physical actions, but make only minor
247   responses, such as pressing switches or levers. Based on this distinction, it has been demonstrated
248   that when actions are based on the first person perspective and involve physical acts, the subjects
249   tend to make more emotional decisions (Amit et al., 2014; Greene et al., 2001). (3) Stealth
250   assessment can be also defined as a performance-based method, in which what is evaluated is latent
251   (Rupp et al., 2010). Under this paradigm, embedding assessments in immersive virtual worlds is an
252   innovative approach (Shute and Spector, 2008) that, in our view, is an improvement from the
253   standpoint of ecological validity. (4) Regarding physiological real-time measurement, VR provides
254   interactive and multimodal sensorial stimuli that provide unique advantages over other
255   methodologies in neuroscientific investigation (Bohil et al., 2011).Thus, due to technological
256   advances, researchers can now use accurate, affordable devices to obtain physiological measures
257   which have been found to be more effective than self-reported measures as they (a) are not intrusive,
258   (b) do no rely on participants' self-assessment of their emotional or cognitive experience and (c) can
259   detect changes in participants in real time. We have previous experience in combining VR
260   technology with brain activity measures, and these results have shown that interactive virtual
261   environments allow the measurement of emotional responses (Marín-Morales et al., 2018).

262

263   Table 1 here

264

265   For these reasons, customizable, domain independent VR environments, in which individuals can, to
266   a certain extent, act freely and react naturally to different risks or hazards, open to researchers an
267   uncharted field of information about risk taking attitudes and behaviours. The set of these
268   requirements may result in an application that includes a virtual environment, with a specific
269   narrative that face the users with risky situations. This should be designed following stealth
270   assessment methodology, and would allow physiological and behavioural measurement to provide
271   information about individual decision making in the field of risk taking. We will show an example of
272   how this tool might perform: the user could be in a virtual environment that consists in a path which
273   (s)he must cover from start to finish, within the shortest possible time. Suddenly, (s)he meets a
274   bifurcation, where (s)he has to choose whether a safe but log way – less risk, less potential benefit -,
275   or a dangerous but short path – higher risk, higher potential benefit -. During this decision making
276   process, we could take measures of galvanic skin response to assess emotional activation, and
277   behavioural measures such as reaction time and the decision made by the user. As a result, we could
278   obtain information about specific weight of emotional processes in risk taking, and its influence on
279   behaviour.

280   Our future research aims to study to what extent a VR tool is able to measure the cognitive and
281   affective processes that influence risk taking. Furthermore, we would focus on how virtual
282   interactions and narratives weight on the decision making process.

283   **6   Conclusion**

284   Risk taking measurement is a major challenge for companies and researchers. Investigations into
285   behavioural measurement are at a turning point as, due to the potential of technological advances, we
286   can generate virtual worlds to evaluate and, going further, train people in certain skills and
287   competences. We suggest that virtual reality is the most appropriate medium for assessing attitudes to
288   risk and risk perception, conditioning factors in the risk taking process, due to their immersive
289   capabilities. We propose to undertake future investigations into real-world risks, embodied
290   interactions, stealth assessment and physiological real-time measurement as differentiating elements
291   in risk taking assessment. If we can study and measure the real, unbiased reactions of people facing
292   risky or hazardous situations, it will be possible to create customized training programmes to fit their
293   individual characteristics. This can be expected to contribute to the improvement of OSH training
294   programmes, reducing work-related incidents and, consequently, costs for companies.

295   **7   Author Contributions**

296   All authors made substantial contributions to the conception and development of the work. MA, CJ
297   and NA are responsible for the general idea of the paper. CJ and JS participated in drafting the work,
298   while JG and MC revised it in-depth and provided new ideas thanks to their previous experience. MA
299   supervised the entire work, revised the manuscript and approved the final version to be submitted.

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9   Conflict of Interest Statement

304 The authors declare that the research was conducted in the absence of any commercial or financial
305 relationships that could be construed as a potential conflict of interest.

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547   **Legends**

548   Figure 1. Individual differences that influence risk taking.

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550   Table 1. VR features and benefits of risk taking measurement.

Domain	VR features	Benefits of measurement
Real-world risks	Evokes the sensation of physical risk	Neural mechanisms similar to real life
Embodied interactions	Actions raised in the first person	More emotional decisions
Stealth assessment	Indirect evaluation in real time	Reduction of test anxiety More validity and reliability
Physiological real-time measurement	Physiological measurement during performance	Involuntary, uncontaminated by participant answering bias

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Figure 01.TIF