Untersuchung des Zusammenhangs von Presence und User Experience in der Virtuellen Realität als Grundlage für die Entwicklung von Trainingssystemen und Medizinprodukten in der Chirurgie

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I Abkürzungsverzeichnis

AR	Augmented Reality
FGL	Formgedächtnislegierung
ITC-SOPI	International Test Commission - Sense of Presence Inventory
SUS	System Usability Scale
UEQ	User Experience Questionnaire
VR	Virtual Reality

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1 Einführung in die Thematik

1.1 Einsatz von Virtual Reality in Medizin und Chirurgie

1.1.1 Virtual Reality für chirurgisches Training und Telechirurgie

Virtual Reality (VR) ermöglicht einer Person, sich durch technische Hilfsmittel in eine virtuelle Welt hineinzuversetzen und in dieser zu interagieren. Eines der ersten VR-basierten chirurgischen Trainingssysteme (s. Abbildung 1) wurde Mitte der 1990er-Jahre für arthroskopische Operationen von Müller et al. entwickelt [1]. Seitdem wurden diese Simulatoren immer weiter verbessert und auf neue endoskopische und minimalinvasive chirurgische Anwendungsgebiete erweitert [2]. So entwickelten Park et al. einen VR-Simulator zur laparoskopischen Durchführung einer Cholezystektomie [3]. Heng et al. demonstrierten das Trainingspotential von VR anhand eines Arthroskopiesimulators [4] und Chen et al. durch die Entwicklung eines VR-basierten Simulators zum Training des Bohrens in das Femur bei einer Hüftfraktur [5]. Evaluationsstudien zeigen, dass VR-basierte chirurgische Trainingssysteme durchaus eine qualitative Verbesserung der chirurgischen Ausbildung darstellen [6–10]. So zeigen die Meta-Reviews von Sturm et al. [6] und Zendejas et al. [7], dass VR-Trainings von laparoskopischen Eingriffen zu besseren Ergebnissen der in Ausbildung befindlichen Chirurgen bei der späteren Durchführung realer Operationen führen. Allerdings blieb der Einsatz VR-basierter chirurgischer Trainingssysteme bis heute auf minimalinvasive Operationen beschränkt. Erst kürzlich wurde ein Großprojekt zur Entwicklung eines Prototyps für die Hüftendoprothetik zum Abschluss gebracht, welcher vom Autor und seiner Projektgruppe konzeptioniert und entwickelt wurde. Dieser Simulator für den nicht-minimalinvasiven orthopädischen Bereich ermöglicht ein VR-basiertes Training, in dem das Ausfräsen eines Acetabulums während des Einsetzens einer Primärendoprothese von Chirurgen trainiert werden kann [11–13].

Abbildung 1: VR-basierte chirurgische Trainingssimulatoren mit haptischem Feedback für laparoskopische (links) [14] und arthroskopische (rechts) [15] Eingriffe.

1.1.2 Virtual Reality in der Therapie und Rehabilitation

Anfang der 1990er-Jahre begann die Erforschung des Einsatzpotentials von VR für psychotherapeutische und Rehabilitations-Therapien (s. Abbildung 2) [16–21]. Psychotherapeutisch wird VR vor allem als Ergänzung bzw. Ersatz für Expositionstherapien verwendet [22, 23]. Der Vorteil von VR liegt hier darin, dass der Realismus des Angstauslösers schrittweise gesteigert werden kann, ohne den Patienten hierdurch einem zusätzlichen Risiko auszusetzen. So kann bspw. bei Akrophobie zunächst ein „Bauklotz“-Szenario verwendet werden, bei dem alle Objekte einfache Quader darstellen. Dann kann der Realismus hin zu einer photorealistischen Szene gesteigert werden. Außerdem kann auch die Tiefe des Abgrunds patientenspezifisch schrittweise erhöht werden. Weitere Einsatzfelder von VR sind u.a. die Behandlung von Agoraphobie [24], Arachnophobie [25], Logophobie [26], Schizophrenie [27, 28] und posttraumatischen Belastungsstörungen [29–33]. Auch in der Suchttherapie findet VR seinen Einsatz [34], indem die Patienten mit suchtauslösenden Situationen konfrontiert werden, bspw. einer Bar. in der getrunken und geraucht wird [35–37]. Auch in der Schmerztherapie von Brandverletzten zeigte VR positive Ergebnisse bei der Patientenbehandlung, indem Sie bspw. während der Physiotherapie ein VR-Spiel spielten. [38–40]. Dabei zeigte sich, dass auch bei wiederholten VR-unterstützten Physiotherapiesitzungen ein signifikant niedrigerer Schmerzpegel von den Patienten berichtet wurde.

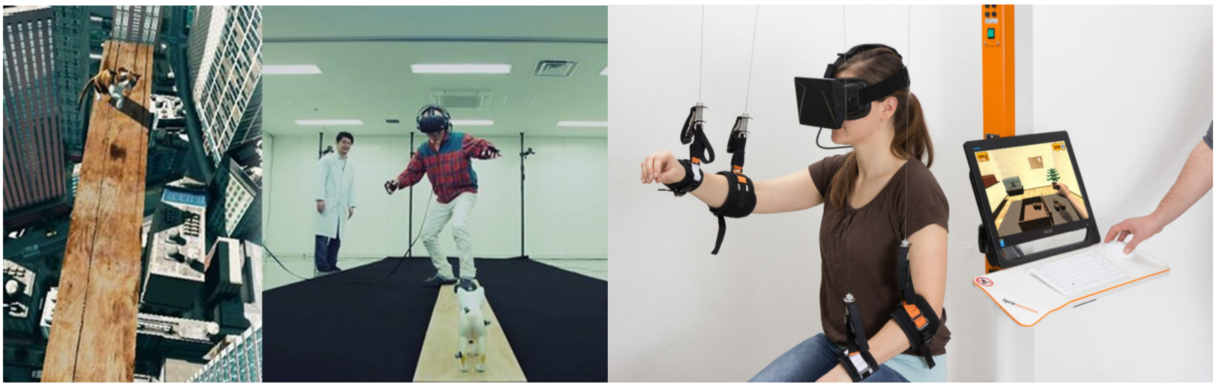

Abbildung 2: VR-Therapie-Anwendung für Akrophobie (links) [41]; VR-Anwendung für die Schlaganfall-Rehabilitation (rechts) [42].

In der Rehabilitation findet VR vor allem bei der Behandlung von neurologischen Funktionseinschränkungen in Folge eines Schlaganfalls [19, 42–44] und der Behandlung von Phantomschmerzen nach Verlust einer Gliedmaße Einsatz [20, 45]. Dabei wird der Patient mittels eines am Kopf getragenen VR-Displays in einen Avatar (virtuellen Körper) versetzt, inklusive gelähmter oder fehlender Gliedmaßen. Zusätzlich wird der Körper des Patienten durch unterschiedliche Verfahren wie etwa Kamerasysteme oder Bewegungsanalyseanzüge erfasst und diese Bewegungen auf den Avatar übertragen. So ausgerüstet führt der Patient anschließend die Therapieaufgaben aus. Im Falle einer gelähmten oder fehlenden Hand wird dann die Bewegung der gesunden Hand direkt auf die andere Hand übertragen. Der Patient bewegt also real seine gesunde Hand, sieht aber stattdessen nur seine andere Hand die

Bewegung ausführen. Beide Therapiemethoden nutzen dabei das Phänomen der „Gummihand-Illusion“ [46–48], dem das Prinzip der Körpertransferillusion zugrunde liegt. Die Illusion besteht darin, dass eine künstliche oder virtuelle Gliedmaße als Teil des eigenen Körpers akzeptiert wird.
Diese Beispiele zeigen, dass durch VR auch das Verhalten auf unterbewusster Ebene beeinflusst werden kann.

1.2 Presence, User Experience und Usability

1.2.1 Begriffe

Zur Einführung in die Thematik der vorliegenden Dissertationsschrift sollen zunächst die wichtigsten Begriffe vorgestellt werden. Deren ursprüngliche Definition erfolgte in englischer Sprache. In dieser Arbeit wird deren englische Form verwendet, da teilweise keine bedeutungsgleichen Übersetzungen im Deutschen existieren, vor allem aber, um eine bessere Wiederauffindbarkeit in den Publikationsmanuskripten in Kapitel 2 sowie der wissenschaftlichen Literatur zu ermöglichen.

Virtual Reality (VR): Die anerkannteste Definition von Virtual Reality stammt von Mann [49] (s. Abbildung 4), welcher das Konzept des Reality-Virtuality-Kontinuums von Milgram et al. [50] (s. Abbildung 3) um Mediality erweiterte. Im Reality-Virtuality-Kontinuum stellt die Realität (z.B. einen OP-Saal) den einen Endpunkt und Virtual Reality den anderen Endpunkt dar. Dabei ist VR eine durch einen Nutzer erlebte, vollkommen künstliche Welt, welche eine Nachbildung der realen Welt darstellen kann (z.B. einen virtuellen OP-Saal), oder aber vollkommen fiktionale Welten, welche nicht den physikalischen Gesetzen unterlegen sein müssen [50]. Zwischen Realität und VR liegt der Bereich der Mixed Reality, der die verschiedenen Kombinationsgrade von realen und virtuellen Elementen umfasst, bspw. die Projektion der Lage von Nerven und Gefäßen auf die Haut eines Patienten für einen besseren operativen Zugang.

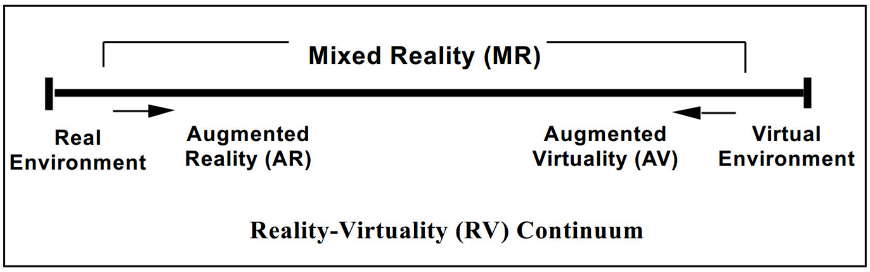

Abbildung 3: Das Reality-Virtuality-Kontinuum nach Milgram et al. [50].

Während sich das Reality-Virtuality-Kontinuum mit dem Inhalt einer Umgebung befasst, bezieht sich die von Mann [49] vorgenommene Erweiterung um Mediality (s. Abbildung 4) auf die Beeinflussung der Wahrnehmungskanäle dieser Umgebung durch den Benutzer. Mediality modifiziert die Wahrnehmung [49]. Beispiele hierfür sind Hörgeräte oder Brillen, welche die Wahrnehmung einer realen aber auch einer virtuellen Umgebung beeinflussen. Aber auch Noxen, wie bspw. Ethanol, Kodein, Cannabioide oder Opioide, beeinflussen die Wahrnehmung und müssen im Kontext von Mediality mitverstanden werden.

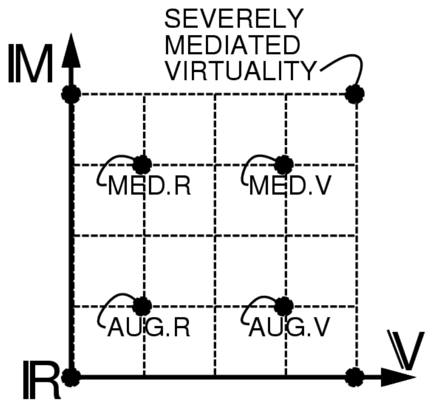

Abbildung 4: Die Taxonomie von Reality, Virtuality und Mediality nach Mann [49].

Immersion: Mit Immersion wird ausschließlich die technische Güte beschrieben, mit der eine VR-Umgebung erstellt wird [51], bspw. die Anzahl an Displays und deren Auflösung, Bildwiederholraten oder der Realismus von Licht und Schatten in virtuellen Szenen. Damit ist Immersion ein objektives Maß, welches verwendet werden kann, um verschiedene VR-Umgebungen zu vergleichen. Slater [51] zieht hier die Analogie zur Wellenlängenverteilung einer Farbe heran.

Presence: Als Presence wird das subjektive Gefühl einer Person verstanden, sich an einem Ort zu befinden. Dies wird häufig mit Immersion verwechselt. Presence und Immersion stellen aber zwei grundlegend verschiedene Sichtweisen dar. So kann eine VR-Umgebung mit dem gleichen Immersionsgrad zwischen verschiedenen Personen ein unterschiedliches Gefühl von Presence erzeugen [51]. Presence folgt aus Immersion, ist allerding nicht dasselbe. Um bei der Farbanalogie von Slater [51] zu bleiben, ist Presence die Wahrnehmung einer Farbe, während Immersion deren Wellenlängenverteilung ist.

User Experience: Nach ISO 9241-210 [52] wird User Experience als die „Wahrnehmung und Reaktion einer Person von der Nutzung und/oder antizipierten Nutzung eines Produktes, Systems oder Dienstes“ (sic. Eigenübersetzung) [52] definiert. Dabei werden explizit alle hedonischen Aspekte der Benutzung eingeschlossen. Hedonische Aspekte beschreiben die nicht-aufgabenbezogenen Bewertungsaspekte einer Person über ein Produkt, wie ihre Einschätzung über die Originalität, den Innovationsgrad, die Neuheit etc. des Produktes. Dabei spielen Faktoren wie das visuelle Design, neue Interaktionstechniken oder Funktionen eine Rolle [53]. User Experience geht auf das subjektive Empfinden eines Nutzers ein und umfasst neben dem emotionalen Empfinden und ästhetischen Aspekten auch die Bedienbarkeit und Nützlichkeit [54]. User Experience beschreibt also die allumfassende Wahrnehmung und Reaktion eines Nutzers während der Benutzung eines Produktes.

Usability: In Abgrenzung zu User Experience definiert die ISO 9241-210 [52] Usability als das „Ausmaß zu welchem ein System, Produkt oder Dienst von einen spezifischen Nutzer benutzt werden kann, um spezifische Ziele effektiv, effizient und zufriedenstellend in einem spezifischen Benutzungskontext zu erreichen“ (sic. Eigenübersetzung) [52]. Usability ist damit eine Teilmenge von User Experience, die sich rein auf die pragmatischen Aspekte bzw. die Zielerfüllung einer Produktnutzung konzentriert und sämtliche hedonischen Aspekte nicht umfasst.

1.2.2 Verwendete Messmethoden für Presence, User Experience und Usability

Im Folgenden werden die in den Publikationsmanuskripten (s. Kapitel 2) verwendeten Messmethoden für Presence, User Experience und Usability vorgestellt. Es handelt sich dabei ausschließlich um etablierte Fragebögen, welche immer in der Nacherhebung einer Studie verwendet werden.

International Test Commission – Sense of Presence Inventory (ITC-SOPI): Der ITC-SOPI wurde von Lessiter et al. [55] entwickelt und ist ein Standard-Fragebogen zur Erhebung der Presence eines Nutzers. Er besteht aus 44 Fragen, die auf einer Fünf-Punkt-Likert-Skala zu beantworten sind. Aus diesen Fragen werden vier Faktoren berechnet.

- Der *Sense of physical space* beschreibt das Gefühl des Nutzers, physisch in der dargestellten Umgebung verortet zu sein, sowie das Gefühl, mit den Objekten zu interagieren und diese kontrollieren zu können [55].
- *Engagement* beschreibt das Interesse und die Involvierung des Nutzers in die dargestellte Umgebung, das Interesse am dargestellten Inhalt sowie die allgemeine Freude an der VR-Erfahrung [55].
- Die *Ecological validity* misst, wie glaubwürdig, realistisch und natürlich sich die dargestellte Umgebung für den Nutzer anfühlt [55].
- *Negative effects* fasst alle nachteiligen Effekte zusammen, die bei einer VR-Erfahrung auftreten können, z.B. Schwindel, leichte Übelkeit oder Kinetose [55].

User Experience Questionnaire (UEQ): Der UEQ ist einer der etabliertesten Fragebögen zur Erhebung von User Experience [56] und besteht aus 26 bipolaren Items, die auf einem siebenstufigen semantischen Differenzial bewertet werden. Er umfasst die folgenden sechs Skalen, die aus den beantworteten 26 bipolaren Items berechnet werden:

- Die *Attractiveness* beschreibt den allgemeinen Eindruck des Nutzers vom Produkt [57].
- *Efficiency* gibt den Eindruck des Nutzers wieder, ob das Produkt schnell und effizient zu bedienen war [57].
- Die *Perspicuit* gibt an, wie einfach das Produkt für den Nutzer verständlich war und wie leicht er sich mit dem Produkt vertraut machen konnte [57].

- *Dependabilty* drückt das Gefühl des Nutzers aus, ob die Interaktion mit dem Produkt sicher und vorhersehbar war, und wie hoch sein Gefühl war, die Interaktion zu kontrollieren [57].
- Die *Stimulation* beschreibt die Einstellung des Nutzers, wie interessant und aufregend das Produkt war und ob er es weiter benutzen würde [57].
- *Novelty* drückt aus, ob das Produktdesign vom Nutzer als innovativ und kreativ empfunden wurde und ob es seine Aufmerksamkeit erregt hat [57].

Diese sechs Skalen des UEQ sind in Gruppen zusammengefasst, welche die Wahrnehmung der hedonischen und pragmatischen Qualitäten eines Produktes durch den Nutzer angeben. Die pragmatische Qualität umfasst typische Usability Faktoren, da sie die aufgabenorientierten Qualitätsaspekte beschreibt. Sie wird aus den Skalen *Efficiency, Perspicuit* und *Dependabilty* gebildet. Die hedonische Qualität besteht aus den Skalen *Stimulation* und *Novelty*. Sie drückt die nicht-aufgabenbezogenen Qualitätsaspekte aus und beschreibt eher ästhetische Eindrücke des Nutzers sowie dessen Freude an der Benutzung des Produktes.

Systems Usability Scale (SUS): Der SUS [58] ist der Industriestandard zur Messung von Usability und wurde über 5000 mal eingesetzt [59]. Der SUS besteht aus zehn Fragen, welche die Effizienz, Effektivität und Zufriedenheit des Nutzers mit dem Produkt misst [58]. Die Beantwortung der Fragen erfolgt mittels einer Fünf-Punkt-Likert-Skala.

1.3 Potentiale von Virtual Reality in der Medizinproduktentwicklung

Neben dem in Abschnitt 1.1 beschriebenen Einsatz von VR für chirurgisches Training, Therapie und Rehabilitation liegen die Potentiale von VR auch in der Medizinproduktentwicklung. Allerdings scheinen diese Potentiale nicht umfänglich genutzt zu werden. Wissenschaftliche Aufarbeitungen zur Thematik sind aktuell faktisch nicht existent. Auch Informationen aus der Medizinproduktindustrie sind Wissenschaftlern wegen kommerzieller Interessen der Hersteller und Entwickler kaum zugänglich. Allerdings scheinen gerade erste Schritte in der Vertriebsunterstützung gegangen zu werden, wie zwei kürzlich erschienene Produktberichte der Zimmer Biomet Holdings Inc. [60] und Stryker Cooperation [61] über VR-Anwendungen nahelegen. Dabei zeigen viele andere Industrien, bspw. Luft- und Raumfahrt, Automobilentwicklung, Maschinen- und Anlagenbau, wie VR bereits seit Jahrzehnten in verschiedenen Phasen von der Produktentwicklung über Produktion und Service bis zum Vertrieb vorteilhaft eingesetzt wird [62–72]. Aus diesen Erfahrungen lassen sich konkrete Einsatzpotenziale auch im Lebenszyklus von Medizinprodukten definieren.

Zu Beginn der Entwicklung eines Medizinproduktes, bspw. eines Narkosegerätes, könnten verschiedene Produktdesigns in der VR bewertet und angepasst werden. Durch die maßstabsgetreue Darstellung können so wesentliche Produktmerkmale wie die Nutzungsergonomie besser als an einem normalen Bildschirmarbeitsplatz entwickelt werden. Dies wird u.a. bereits erfolgreich beim Design von Haushaltsgeräten eingesetzt [73].

Wenn ein detailliert auskonstruiertes virtuelles Modell eines Medizinproduktes vorhanden ist, kann dieses in einer VR-basierten interdisziplinären Konstruktionsbewertung mit Mitarbeitern aus Konstruktion, Vertrieb, Service und Produktionsplanung diskutiert werden. Auch hier schafft die maßstabsgetreue Darstellung in VR eine bessere Verständnisgrundlage für alle Beteiligten, sodass Fehler, die z.B. die Montage oder die Wartung erschweren würden, durch Konstruktionsänderungen vermieden werden können. Erfolgreich wird dies u.a. im Werkzeugmaschinenbau eingesetzt [74].

Da auch bei Medizinprodukten die User Experience und Usability über deren Erfolg mitentscheiden, ist die frühe Einbeziehung der Nutzer sehr wichtig. VR bietet hier die Möglichkeit, Nutzerstudien mit einem rein virtuellen Medizinprodukt durchzuführen und so noch während der Konstruktionsphase Verbesserungen in das Medizinprodukt einfließen zu lassen. Eines der ersten Beispiele im Medizinproduktebereich, welches dieses Potential verdeutlicht, ist eine Nutzerstudie zur Entwicklung eines chirurgischen Saug-/Spülsystems, an dem der Autor beteiligt war [75]. Für dieses System sollte eine Nutzungsbewertung durch Chirurgen anhand des rein virtuellen Prototyps stattfinden (s. Abbildung 5) [75]. Die Erwartung an dieses neu zu konstruierende chirurgische Saug-/ Spülsystem war, dass das Saug-/Spülrohr aus einer Formgedächtnislegierung (FGL) besteht. FGL besitzt die Eigenschaft, sich durch thermale Aktivierung in eine beliebige eingeprägte Form zurückzuverwandeln. Das ursprüngliche Nutzungskonzept des FGL-Saug-/Spülsystems sah vor, dass das FGL-Rohr in gerader Form in den Patienten eingeführt wird und durch Aktivierung mit warmen Spülwasser eine eingeprägte anatomische Form annimmt. Die vom Autor durchgeführte VR-Nutzerstudie ergab, dass dieses Aktivierungsprinzip aus chirurgischer Sicht gar nicht erwünscht war [75]. Durch diese VR-Nutzerstudie konnte so in einer frühen Entwicklungsphase eine Fehlentwicklung vermieden werden. Ähnliche Einsatzszenarien finden sich bspw. in der Automobilindustrie [76].

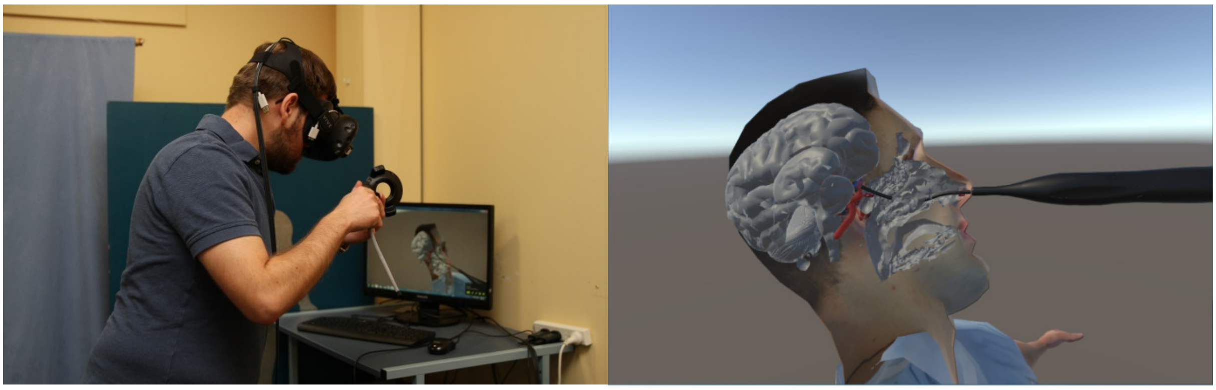

Abbildung 5: VR-Evaluationsumgebung zur virtuellen Erprobung eines neuartigen Saug-/Spülsystems (links); Beispielszene des virtuellen Szenarios für die Produktevaluierung (rechts).

1.4 Motivation und Ziele der Arbeit

Im Abschnitt 1.1 wurde gezeigt, wie vielfältig und weitverbreitet VR-Anwendungen bereits im medizinischen Bereich zur Aus- und Weiterbildung von Ärzten sowie für die Therapie von Krankheiten eingesetzt werden. Das Potential, welches durch VR bei der Entwicklung von Medizinprodukten erschlossen werden könnte, wurde im Abschnitt 1.3 erläutert. Daran zeigt sich, wie wichtig das Verständnis von Presence im Zusammenspiel mit User Experience und Usability ist, da diese Faktoren wesentlich über die Qualität und den Erfolg von medizinischen VR-Anwendungen entscheiden. Daher Ist überraschend, wie wenig über dieses komplexe Zusammenspiel bekannt ist.

Das Ziel dieser Arbeit war es daher, grundlegende Erkenntnisse über den Zusammenhang von Presence, User Experience und Usability zu gewinnen und zu untersuchen, welchen Einfluss Alltagsfaktoren darauf haben könnten (s. Abbildung 6). Im Folgenden werden die drei Ziele dieser Arbeit definiert und deren Motivation und Relevanz hergeleitet.

Ziel 1: Für chirurgische VR-Trainingssysteme ist das Zusammenspiel von Presence mit User Experience und Usability wesentlich, um einen guten Trainingssimulator zu entwickeln, der von Chirurgen akzeptiert wird und einen hohen Trainingserfolg erzielt. Da Presence bestimmt, wie sehr sich eine Person in die virtuelle Welt hineinversetzt fühlt, ist sie Grundlage für einen guten chirurgischen VR-Trainingssimulator. Eine hohe User Experience und Usability steigert die Akzeptanz, solch ein System zu nutzen. Wenn ein chirurgisches VR-Trainingssystem schlecht zu bedienen ist, steigt das Risiko, dass es nicht benutzt wird. Weiterhin ist der Trainingserfolg geringer als bei einem chirurgischen VR-Trainingssystem mit guter User Experience und Usability.

Obwohl etablierte Methoden sowohl zur Messung von User Experience als auch von Usability bestehen, sind diese entwickelt worden, um Produkte in der Realität zu testen. Die Qualität von VR-Szenarien ist mittlerweile sehr hoch. Dennoch weicht deren Qualität, wie bei jeder anderen Simulation, von der Realität ab. Negative Effekte wie Schwindel, Übelkeit und dergleichen, auch als Cybersickness oder Simulatorkrankheit bezeichnet, zeigen eindrucksvoll, dass durch die nicht perfekte Simulation der Realität kurzfristige und vorübergehende körperliche Beeinträchtigungen ausgelöst werden können. Deswegen kann nicht automatisch davon ausgegangen werden, dass in VR dieselbe Presence wie in der Realität verspürt wird und die wahrgenommene User Experience und Usability davon unbeeinträchtigt bleibt. Entsprechend könnte also ein an sich funktional guter chirurgischer VR-Trainingssimulator durch eine schlechte Presence negativ beeinflusst werden, sodass er nicht genutzt wird, oder schlechtere Trainingsergebnisse erzielt werden. Daher war das **erste Ziel** dieser Arbeit, den genauen Wirkzusammenhang von Presence mit User Experience und Usability zu ergründen, damit Entwickler solcher chirurgischer VR-Trainingssysteme wissen, worauf bei deren Entwicklung geachtet werden muss (s. Abbildung 6).

Ziel 2: Auch bei der Entwicklung von Medizinprodukten ist ein Verständnis des Wirkzusammenhanges von Presence mit User Experience und Usability unabdingbar. Produkte mit hoher User Experience und Usability haben größere Marktchancen und sind effektiver im Gebrauch. Umso wichtiger ist es daher die späteren Nutzer, im vorliegenden Fall Ärzte, bei der Entwicklung von Medizinprodukten frühzeitig in die Entwicklung einzubeziehen. Dies kann besonders früh geschehen, indem entsprechende Nutzerstudien nicht erst relativ spät im Entwicklungsprozess mit physischen Prototypen erfolgen, sondern bereits frühzeitig in VR mit dem virtuellen Prototyp. Trotz der großen Vorteile durch die frühzeitige Evaluation gibt es dabei folgendes Problem: Sämtliche existente Fragebögen zur Evaluation von User Experience und Usability wurden für Tests in der Realität mit realen Produkten entwickelt. Daher ist es unbekannt, welchen Einfluss Presence auf deren Bewertung hat. Es ist also fraglich, ob die Probanden den virtuellen Prototyp eines Medizinprodukts genauso bewerten wie einen physischen. Dies zu wissen ist jedoch von Bedeutung, da durch eine Verzerrung der Studienergebnisse eine Analyse erfolgen könnte, die zu Fehlentscheidungen bzgl. der Verbesserung des Medizinproduktes führen würde. Im vorbeschriebenen Fall des Saug-/Spülsystems wäre somit bei einer schlechten Presence eine negativere Bewertung der User Experience und Usability des Medizinprodukts durch die evaluierenden Ärzte im Vergleich mit einem physischen Prototypen möglich gewesen. Deswegen ist eine tiefe Kenntnis, wie Presence die User Experience und die Usability beeinflusst, wichtig. Das **zweite Ziel** dieser Arbeit bestand daher darin zu bestimmen, ob und ggf. welche Unterschiede bei der Bewertung der User Experience und Usability eines Produktes in VR im Vergleich zur Realität auftreten und welchen Einfluss Presence darauf hat (s. Abbildung 6).

Ziel 3: Presence steht in direkter Verbindung zur Wahrnehmung, zu kognitiven Prozessen und zu Emotionen. Zunächst müssen in einem virtuellen Szenario die Sinne einer Person angesprochen und somit dem individuellen Wahrnehmungssystem zugänglich gemacht werden. Danach muss dieser künstliche sensorische Input kognitiv verarbeitet und mit anderen Sinneswahrnehmungen integriert werden. In Abhängigkeit von der Qualität des sensorischen Inputs und seiner kognitiven Verarbeitung stellt sich bei der Person, welche sich in einem VR-Szenario befindet, ein mehr oder weniger starkes Gefühl ein, gegenwärtig in der virtuellen Welt zu sein. Aus diesem Gefühl resultiert der wahrgenommene Grad an Presence. In Abhängigkeit davon, wie involviert die Person in das virtuelle Szenario ist, können bei ihr – je nach Inhalt des virtuellen Szenarios – verschiedene Emotionen ausgelöst werden. Ein Beispiel hierfür wäre die Auslösung von Ängsten bei Arachnophobie-Patienten während ihrer Begegnungen mit virtuellen Spinnen als Teil der Behandlung [17]. Allerdings kann bereits das reine Verspüren von Presence in einem virtuellen Szenario Emotionen wie Aufgeregtheit oder Unwohlsein hervorrufen [77].

Die Verbindung von User Experience, Usability, Wahrnehmung, kognitiver Verarbeitung und Emotionen erscheint offensichtlicher. Eine Anwendung muss schließlich mit dem sensorischen System einer

Person wahrgenommen werden, damit die Person die Anwendung benutzen kann. Das Erlernen, wie diese Anwendung zu benutzen ist, und das Benutzen selbst sind kognitive Leistungen. Die Nutzungserfahrung der Anwendung führt schließlich zu einer Einstellung und Meinungsbildung gegenüber dem Produkt.

Wahrnehmung, kognitive Verarbeitung und Emotionsausprägung können allerdings durch verschiedene psychotrope Substanzen wie Ethanol, Kodein, Amphetamine, Opioide, Beruhigungsmittel und ähnliche Substanzen beeinträchtigt werden. Ethanol kann u.a. die Kontrastwahrnehmung beeinflussen, zu verschwommenem Sehen führen, Entscheidungsprozesse beeinträchtigen und die Emotionskontrolle verändern [78–82]. Gerade auch im operativen Umfeld sind Ärzte während chirurgischer Eingriffe am Patienten konstant geringen Mengen an Narkosegasen ausgesetzt. Aufgrund der Allgegenwärtigkeit solcher Noxen im medizinischen Feld sind diese als Alltagsfaktor zu betrachten. Daher ist ein Verständnis des Wirkzusammenhangs dieser Alltagsfaktoren auf Presence, User Experience und Usability für jede medizinische VR-Anwendung wichtig, um bspw. mögliche Lernerfolgseinschränkungen oder Wahrnehmungsverzerrungen während der Nutzung von VR-Trainingssystemen entgegenwirken zu können.

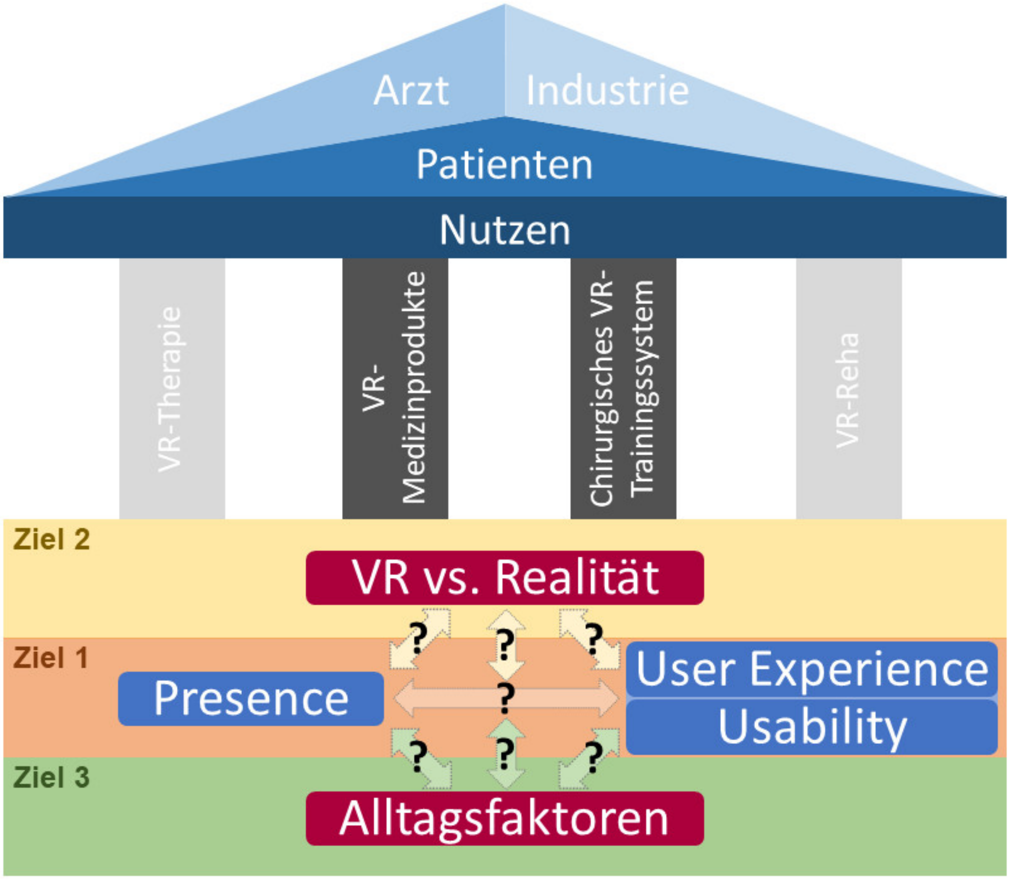

Abbildung 6: Übersicht des Zusammenhangs der untersuchten Modelle (blau) und Einflussfaktoren (rot). Die Pfeile zeigen die in dieser Arbeit untersuchten unbekannten Zusammenhänge zwischen diesen Modellen und Einflussfaktoren. Die verschiedenfarbigen Hintergründe zeigen, welche Zusammenhänge mit den drei Zielen dieser Arbeit korrespondieren.

Auch auf therapeutischem Gebiet, bspw. der Behandlung von posttraumatischen Belastungsstörungen oder Phobien, ist das Verständnis von Alltagsfaktoren auf Presence, User Experience und Usability von hoher Relevanz. So nehmen diese Patienten oft Psychopharmaka ein und leiden häufig noch an einer Alkoholsucht [83, 84]. Für den Einstieg in dieses Forschungsgebiet scheint daher der Alltagsfaktor Ethanol besonders geeignet und relevant. Die Wirkung von Ethanol auf Wahrnehmung, kognitive Prozesse und Emotionen wird seit Jahrzehnten erforscht und ist gut bekannt. Zudem ist Ethanol weltweit allgegenwärtig und wird von großen Teilen der Weltbevölkerung konsumiert [85]. Trotz dieser Relevanz sind die Auswirkungen der beschriebenen Alltagsfaktoren auf Presence, User Experience und Usability selbst in Ansätzen unbekannt. Daher existieren hierzu auch keine etablierten Methoden. Das **dritte Ziel** dieser Arbeit war es daher, den methodischen Weg für die Evaluation der Wirkung von Alltagsfaktoren auf Presence, User Experience und Usability zu ebnen und anhand einer ersten explorativen Studie für niederdosierte Ethanolmengen zu evaluieren (s. Abbildung 6).

Zusammenfassend sollen in dieser Arbeit Grundvoraussetzungen für die Nutzbarmachung der Potentiale von VR für die chirurgische Ausbildung (z.B. Simulatoren-basiertes Training) und Medizinproduktentwicklung mit der Ableitung von Handlungsempfehlungen auf Grundlage psychologischer Faktoren evaluiert werden. Dadurch sollen in Zukunft VR-Anwendungen für die Medizin noch attraktiver werden.

Da sich die Erforschung des Zusammenhangs von Presence mit User Experience und Usability insgesamt in den Anfängen befindet, sind gezielt Probanden aus der Allgemeinbevölkerung für die vorliegenden Untersuchungen als Stichprobe gewählt worden. So sollten zunächst Baseline-Daten erhoben werden, aus denen generelle Schlüsse für die Entwicklung chirurgischer VR-Trainingssysteme sowie der Testung von Medizinprodukten in VR durch die späteren Anwender gezogen werden können. Weiterhin schafft die Erhebung dieser Baseline-Daten die Grundlage für einen Vergleich verschiedener Kohorten medizinischen Personals in weiterführenden Arbeiten.

1.5 Experimenteller Aufbau

1.5.1 Studienaufbau

Für die Untersuchung der Interaktion von Presence mit User Experience und Usability im Vergleich von realen und virtuellen Umgebungen sowie unter dem Einfluss von Alltagsfaktoren wurden zwei Studien durchgeführt. Damit eine Vergleichbarkeit der Ergebnisse beider Studien gewährleistet ist, wurde dieselbe experimentelle Aufgabe verwendet. Als experimentelle Aufgabe wurde ein abstraktes, bewusst nicht-medizinisches Evaluationsszenario gewählt um Baseline-Daten zu erhalten. Die experimentelle Aufgabe bestand darin, mittels einer Geocaching-Smartphone-App verschiedene Orte in der Chemnitzer Innenstadt zu finden. Dabei sahen die Probanden auf der Geocaching-App ihren Standort und den Zielort, zu dem sie sich hinbewegen müssen. Bei Erreichen des Zielortes erschien eine Erfolgsmeldung und im Anschluss der nächste Zielort (s. Abbildung 7). Insgesamt mussten sieben Zielorte gefunden werden, wobei die Probanden am Schluss wieder am Startpunkt ankamen.

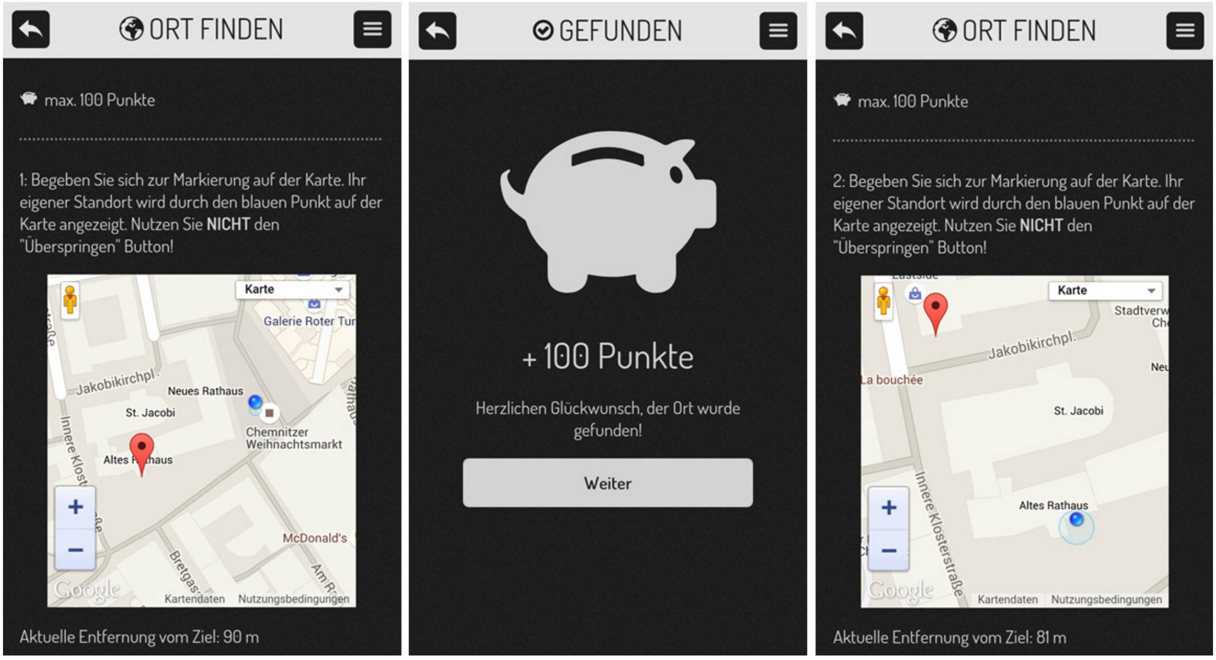

Abbildung 7: Ablauf der Geocaching-App. Anzeige des Ortes der gefunden werden musste (links). Erfolgsbildschirm, wenn Ort gefunden wurde (Mitte). Der nächste Ort der zu finden war (rechts).

Die erst Studie war als between-subject-Design konzipiert (s. Abbildung 8) und bestand aus drei Phasen: (1) Vorerhebung demographischer Daten, (2) Durchführung der experimentellen Aufgabe, (3) Nacherhebung von Presence-, User Experience- und Usability-Daten. Die in Phase 1 erhobenen demographischen Daten umfassten Alter, Geschlecht, Bildungsabschluss, Vorerfahrung mit Geocaching, Vorerfahrung mit VR, Selbsteinschätzung des Lesens einer Papier-Landkarte und die Selbsteinschätzung des Lesens einer elektronischen Landkarte. Für Phase 2, der Durchführung der experimentellen Aufgabe, wurden die Probanden zufällig einer von zwei Gruppen zugeordnet. In der ersten Gruppe führten die Studienteilnehmer die experimentelle Aufgabe in der realen Chemnitzer Innenstadt aus. Die zweite Gruppe ging in einer VR-Umgebung durch die virtuelle Chemnitzer Innenstadt, benutzte aber ein reales Smartphone mit der Geocaching-App. In Phase 3 füllten alle Studienteilnehmer den Presence-Fragebogen ITC-SOPI, den User-Experience Fragebogen UEQ und den Usability-Fragebogen SUS aus.

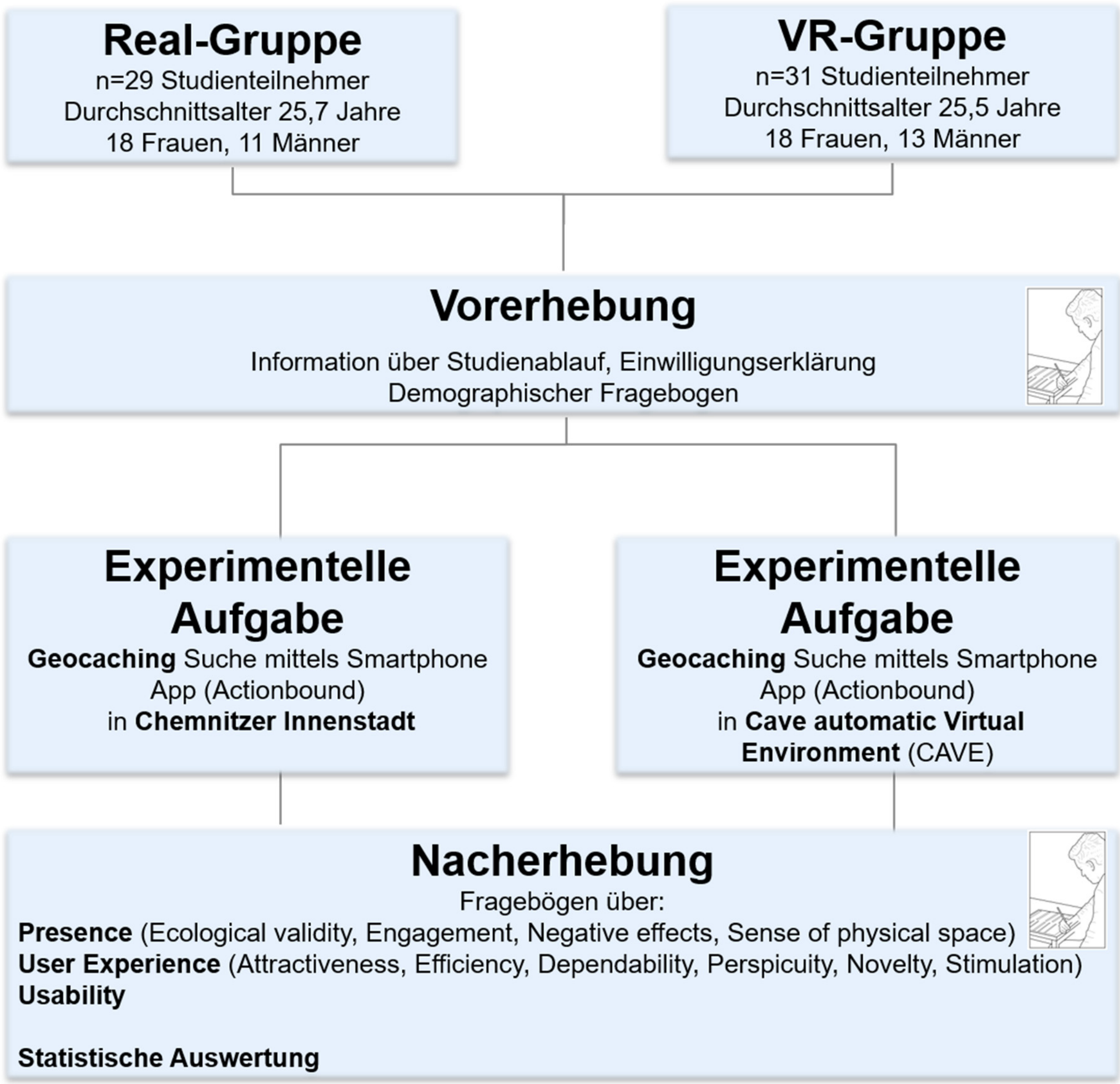

Abbildung 8: Studienablauf der ersten Studie (nach [86]).

Auch die zweite Studie war als between-subject-Design konzipiert (s. Abbildung 9) und in dieselben drei Phasen unterteilt: (1) Vorerhebung demographischer Daten, (2) Durchführung der experimentellen Aufgabe, (3) Nacherhebung von Presence-, User Experience- und Usability-Daten. In Phase 1 wurden dieselben demographischen Daten wie bei der ersten Studie erhoben. Phase 2 ist im Vergleich zu Phase 2 der ersten Studie leicht abgeändert worden, um die Aufnahme einer niedrigen Dosis des Alltagsfaktors Ethanol zu integrieren. Zunächst wurde eine initiale Bestimmung des Atemalkohols durchgeführt, um sicherzustellen, dass die Studienteilnehmer komplett nüchtern waren. Im Anschluss erfolgte die Aufnahme einer kleinen standardisierten Mahlzeit (ein halbes Brötchen mit Käse) und die Einnahme des Ethanols. Die Dosis wurde nach der Widmark-Formel mit der Erweiterung von Watson [87] für jeden Studienteilnehmer so bestimmt, dass ein Alkoholpegel vom 0,4 Promille nicht überschritten wurde. Der Wert von 0,4 Promille wurde gewählt, um zunächst Effekte bei einem niedrigen Alkoholpegel zu untersuchen, bei dem bekannt ist, dass sich erste subtile Beeinträchtigungen zeigen [88]. Nach der vollständigen Einnahme der Ethanol-Dosis warteten die Studienteilnehmer

30 Minuten. Nun wurde der Alkoholpegel mittels Atemmessung bestimmt. Im Anschluss führten die Studienteilnehmer die experimentelle Aufgabe in der VR Umgebung durch. Direkt danach wurde der Alkoholpegel mittels Atemmessung ein drittes Mal bestimmt. Im Anschluss füllten die Studienteilnehmer in Phase 3 der Studie die Fragebögen zu Presence (ITC-SOPI), User Experience (UEQ) und Usability (SUS) aus. Als Kontrollgruppe dienten die Ergebnisse der zweiten Gruppe der ersten Studie, welche die experimentelle Aufgabe nüchtern in der VR-Umgebung durchgeführt hatten. Da die experimentelle Aufgabe und die erhobenen Daten identisch waren, ist ein Vergleich der Daten zulässig.

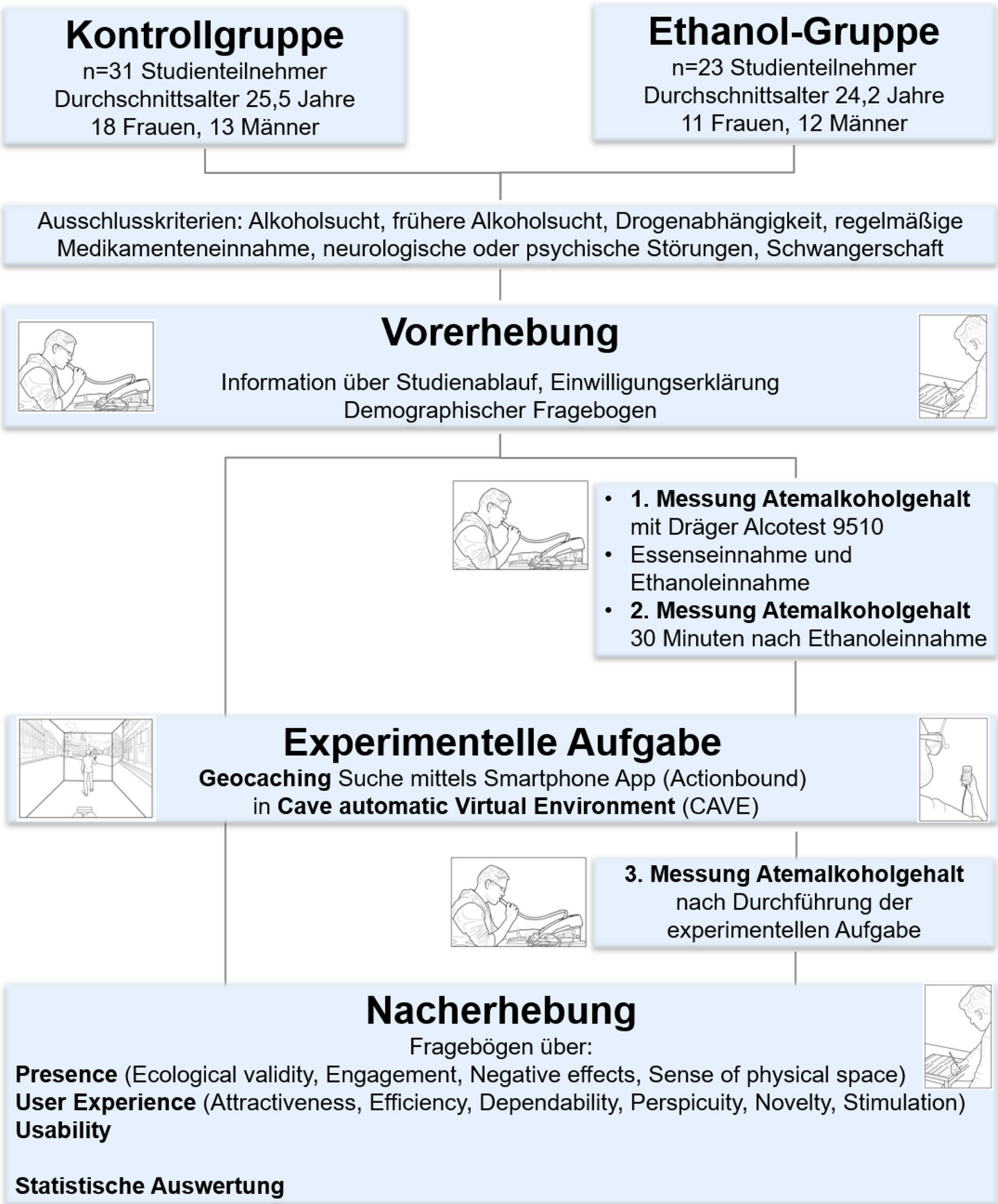

Abbildung 9: Studienablauf der zweiten Studie (Eigenübersetzung aus [86]).

1.5.2 Experimentaltechnik

Zur Erstellung der Geocaching-App wurde die „Actionbound App“ von Zwick und Rauprich verwendet [89]. Das Modell „Google Nexus“ diente als Smartphone in allen Gruppen. Als virtuelle Testumgebung wurde die 5-Seiten-CAVE (Cave Automated Virtual Environment) der Professur Werkzeugmaschinenkonstruktion und Umformtechnik der Technischen Universität Chemnitz genutzt, welche auf dem Grundprinzip von Cruz-Neira et al. basiert [90, 91] (s. Abbildung 10). Diese CAVE ist würfelartig aufgebaut und hat eine Kantenlänge von drei Metern, sodass die Testpersonen beim Betreten der CAVE komplett in die virtuelle Welt eintauchten und ihr gesamtes Sichtfeld abgedeckt wurde. Die CAVE verfügt über einen Cluster von elf Computern, die mit NVidia Quadro 6000-Grafikkarten ausgestattet sind. Die Bilder der CAVE werden über zwanzig Full-HD-Projektoren per zirkular polarisierter Rückprojektion auf die fünf Wände gestrahlt. Ein optisches Infrarot-Trackingsystem mit sechs Kameras der ART GmbH wird zum Tracking verwendet. Das Tracking des verwendeten Smartphones in der CAVE erfolgte über künstliche GPS-Signale [86]. Da die Testpersonen in der CAVE aufgrund der räumlichen Einschränkungen nicht physisch durch das virtuelle Chemnitz laufen konnten wurde die Navigationsmethode von Lorenz et al. [92] verwendet. Dabei wurden die Körperbewegungen der Testperson von hinten mittels eines Microsoft Kinect-Sensors erfasst. Durch das Nach-vorn-Schieben des rechten Fußes bewegte sich die Testperson in der virtuellen Welt translatorisch vorwärts. Wurde der rechte Fuß zurückgesetzt, bewegte sie sich zurück. Die Drehung in der virtuellen Welt erfolgte über eine Drehung der Schultern in die gewünschte Richtung. Drehung und translatorische Bewegung konnten dabei kombiniert werden. Diese Navigationsmethode wurde bereits von Busch et al. in einem ähnlichen virtuellen Szenario eingesetzt [93].

Zur Bestimmung des Alkoholpegels der Studienteilnehmer wurde der Alcotest 9510 der Firma Dräger verwendet (s. Abbildung 11), welcher als einziges Atemalkoholmessgerät vor deutschen Gerichten als Beweismittel zulässig ist. Die Messweite des Alcotest 9510 beträgt 0-3 mg/l bei einer Standartabweichung von < 0,006 mg/l. Eine Messung dauert zirka fünf Minuten, wobei der angezeigte Messwert als Mittelwert aus zwei direkt hintereinander stattfindenden Einzelmessungen hervorgeht.

Abbildung 10: Proband in der CAVE während der Durchführung des Experiments.

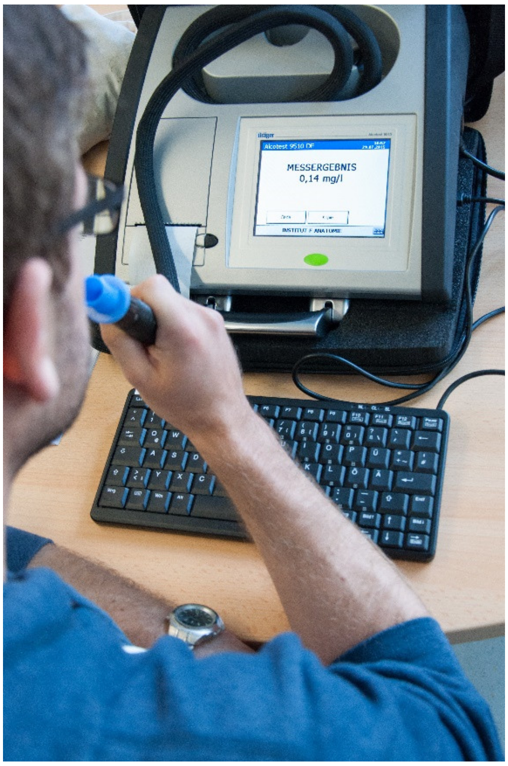

Abbildung 11: Der Dräger Alcotest 9510 in der Benutzung.

2 Publikationsmanuskripte

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Being there again – Presence in real and virtual environments and its relation to usability and user experience using a mobile navigation task

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ABSTRACT

The possibility of using virtual environments instead of real field or laboratory environments is a promising research field. However, before virtual environments are able to replace the traditional environments the differences between the methods must be worked out. We take up on previous studies which compared different real and virtual environments concerning presence and usability and expand the research on the factor of user experience. We compared a virtual field environment (CAVE – Cave Automatic Virtual Environment) and a real field environment (city center of Chemnitz, Germany) in a between-subject-design concerning presence, and evaluate its impact on the usability and the user experience of a geocaching game. The data of 60 participants was analyzed and shows significantly higher ecological validity for the real field environment but higher values for engagement and negative effects in the virtual field environment. Concerning usability, significant differences were verified between the two environments. All presence factors correlated significantly with usability in the CAVE, but did not correlate in the real-field environment. Concerning user experience, the CAVE showed significantly higher hedonic quality values, whereas the real field environment had higher pragmatic quality values. In both conditions presence and user experience factors were partly correlated. Our results indicate that virtual environments can be an alternative to real environments for user experience studies, when a high presence is achieved.

1. Introduction

Technical inventions such as interactive maps are increasingly enriching our lives. These applications do not only show the places of interest, but they also track the user's position, provide the best local traffic route, reveal which restaurant is nearby and how other users rated it. However, comprehensive information is not satisfactory for the user. Two factors – usability and user experience (defined in Table 1) – are essential for interactive products and therefore for mobile navigation applications. Both factors determine the success of a product, because a good usability supports us when using applications and a good user experience leads to using an application with pleasure.

Typically, researchers conduct field or laboratory studies to get products or systems evaluated by users. Both of these settings exhibit different strengths and weaknesses: field studies are more ecologically valid but confounding variables can be less controlled, whereas laboratory studies are characterized by better experimental control, but are less realistic to participants. The use of virtual environments offers the possibility to combine the benefits of both environments (Loomis et al., 1999). Due to advances in the field of virtual reality (VR), a variety of systems are providing a lot of different options for human computer interaction studies. However when using such VR systems for these kinds of studies, they have to meet high requirements concerning realistic visualization and a plausible storytelling. Without a convincing presentation of the setting, the user will not have the feeling of being in the mediated environment and the benefits of the virtual setting compared to laboratory or field studies are nullified. This phenomenon is described by the term "presence", the participant's

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1071-5819/

Table 1
Definition of the factors usability, user experience and presence.

Factor	Definition
Usability	Usability describes the fitness of use of a product and summarizes pragmatic aspects of the product or system. Contrary to user experience, usability does not respect hedonic quality aspects.
User experience	User experience is characterized as "a person's perceptions and response that result from the use or anticipated use of a product, system or service" (Law et al., 2009). User experience includes the holistic assessment of the user because it extends common usability factors with aesthetics, joy-of-use and attractiveness (Rauschenberger et al., 2013).
Presence	Presence is described as the "sense of being in the virtual environment" and is seen as a cognitive state that results from information processing of stimuli in the environment from various senses (Slater and Wilbur, 1997).

feeling of "being there" (Barfield et al., 1995) (see Table 1).

Because of the advantages of virtual environments, it might be reasonable to use them instead of field or laboratory environments for product evaluation studies. However, we must first examine the influence of the environment on the perceived presence. Some studies research the concept of presence in different virtual environments (Gorini et al., 2011; Lorenz et al., 2015; Tang et al., 2004), whereas others compare virtual and real environments concerning perceived presence (Busch et al., 2014; Mania, 2001; Mania and Chalmers, 2004; Nisenfeld, 2003; Usoh et al., 2000). But only one study by Busch et al. (2014) directly addressed influences on presence and usability caused by different environments (virtual versus real laboratory). Unfortunately, this study lacks the comparison of virtual and real laboratory environments in terms of user experience, as well as the evaluation of a real field environment. As described in Table 1 it is insufficient to consider usability alone and it is also important to compare both kinds of environments with virtual environments to make meaningful statements. In addition, in this said study investigating usability, user experience was not considered. Only the fitness of use was assessed but not the acceptance.

Our study tries to approach the fundamental understanding of the relationships between presence, usability and user experience by examining them using a mobile navigation task in a virtual and a real field environment. Our results were in line with previous studies (Busch et al., 2014) and confirmed that a virtual field environment may be used as a substitute for a field environment even if the influences of presence have to be considered. The results showed a positive connection of a virtual field environment and hedonic qualities and confirmed the effect of usability on perceived presence. We offer guidance for usability and user experience researchers and practitioners for performing virtual user experience and usability product evaluations and discover important factors that have to be considered for the interpretation of the results.

The results presented in this paper are part of larger study and relevant for different scientific areas. The parts of the results that are important for an industrial/ergonomic viewpoint were cited in (Brade et al., 2016), where we concentrated on discussing the benefits virtual reality offers for the user. In (Brade et al., 2016) we show how traditional industrial approaches for product development can benefit from using virtual environments in industrial product development to increase productivity. Contrary to this, the results are interpreted from the psychological viewpoint in this paper.

2. Related work

2.1. *Presence in real and virtual environments*

Virtual reality provides the possibility to immerse someone into a computer-generated environment. To understand the differences between the technical aspects necessary to immerse someone, and a person's psychological involvement in a virtual scenario it is important that one understands the differences between the terms immersion and presence and how they are related. Slater and Wilbur (1997) define immersion as "a description of a technology, and describes the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant". Whereas presence is described as in Table 1. The perceived presence is therefore influenced by the level of immersion in different virtual environments. Coelho et al. (2006) divides the concept of presence into media and inner presence; the experience of presence resulting from a set of parameters of a medium that enables the virtual environment, is known as media presence. This technological definition disregards the involvement of psychological components; therefore they are included in the definition of inner presence: which is the psychological experience of the virtual environment, including human perception, cognition and psychomotor capacities. For our study we relate to the concept of inner presence as we examine the psychological experience.

In order to measure presence, Schuemie et al. (2001) list several methods that can be divided into subjective (using questionnaires) and objective measures, with post-experiment questionnaires being the most common approach for assessment. One of the most validated questionnaires, the Independent Television Commission Sense of Presence Inventory (ITC-SOPI) by Lessister et al. (2001), has been used previously within the literature (Busch et al., 2014; Usoh et al., 2000; Nisenfeld, 2003; Tang et al., 2004; Gorini et al., 2011) and was shown to produce reliable results.

Several studies have researched the effects of presence in virtual environments: Gorini et al. (2011) compared the effects of using an external computer screen with a virtual environment that utilized a head-mounted display (HMD) when assessing presence in a virtual hospital task. Presence values were significantly higher for all items of the questionnaires ITC-SOPI and University London College Questionnaire (UCL) (Slater et al., 1994) in the immersive HMD condition. Comparatively, Tang et al. (2004) also utilized a HMD, but compared it with an augmented reality (AR) environment and showed significantly higher values for the presence factor *sense of physical space* for the AR environment. However, there were no significant differences concerning the other factors of the ITC-SOPI questionnaire.

The study of Usoh et al. (2000), which was extended by Nisenfeld (2003), also compares a HMD virtual environment with a real environment. The authors assessed presence by using the ITC-SOPI questionnaire and found significantly higher presence values for the real environment as well as a significantly increased, sense of physical space and ecological validity. Simultaneously, significantly higher values for the negative effects scale for the virtual environment were recorded. This study is very relevant for our work, but disregarded the examination of user-oriented factors between real and virtual environments. Another study that assessed presence and usability when comparing a laboratory environment with a specific type of virtual field environment, the five-sided Cave Automatic Virtual Environment (CAVE), is the work of Busch et al. (2014). The differences between the environments concerning usability (assessed with the System Usability Scale (SUS) by Brooke (1996)) and presence (measured with the ITC-SOPI questionnaire) showed significantly higher values for engagement and the negative effect scale for the virtual field environment. Similarly, significantly higher values for the ecological validity scale in the real laboratory environment were observed. The authors did not find significant differences concerning usability between the two conditions, but they found correlations between the presence factors and the usability for both environments. The sense of physical space was positively associated with usability in both environments. Furthermore, engagement and negative effects also correlated significantly in the virtual field environment, while ecological validity correlated significantly with usability in the real laboratory environment. These results are most relevant for our present work, because Busch et al. (2014) examined the connection of presence and usability in different environments for the first time. However, they only addressed the pragmatic quality of a product and left out the important factor of user experience.

2.2. User experience in virtual environments

All relevant aspects for the subjective assessment of a product are summarized by the term "user experience" (Hassenzahl and Tractinsky, 2006) (see Table 1). The assessment of user experience for interactive products in real field and laboratory studies has become very common. However, the evaluation of user experience in virtual environments has not yet been undertaken. Using virtual environments for user experience evaluations may lead to better/improved cost efficiency and simultaneously require less effort for the technical scenario setup than field or laboratory environments, but before these benefits eventuate, it is necessary to prove the ecological validity of evaluations in virtual environments. Until now, few studies have recognized the importance of investigating user experience in virtual environments: Sylaiou et al. (2010) conducted a mixed reality usability study with 29 participants to examine the relationship between presence and enjoyment. Comparing a museum visit in an AR environment with a real environment, the results showed a significant correlation between enjoyment and presence and a high level of presence was associated with satisfaction and gratification. These findings support a decision to choose a highly immersive virtual environment to reach a high presence to increase the positive feelings of the user during the task performance.

Albrecht et al. (2013) compared a mobile AR learning environment (mARble) with a real learning environment – a textbook. They conducted a study with ten students and measured learning success, usability, and pragmatic and hedonic quality. The assessment analysis showed that the AR supported learning group could acquire more knowledge and had significantly more positive ratings concerning hedonic quality when compared to the control group (no AR support); however, no significant differences for pragmatic quality were observed. Moreover, the results of this study should be interpreted with caution due to the small number of participants. Finally, a meta-analysis Patel and Nichols (2004) addressing presence, usability and enjoyment in different VR systems (including a CAVE, Powerwall, HMD and desktop systems) has shown that desktop systems are less enjoyable than HMDs and projective systems while the CAVE is deemed the most pleasurable system. The authors also found a significantly positive correlation between presence and enjoyment.

2.3. Usability in different environments

One part of user experience is the term usability (see Table 1). Comparative studies in laboratory, field and virtual environments show conflicting findings concerning usability. Kaikkonen et al. (2005) did not find significant differences between the number, or severity of these usability problems, or task performance time between laboratory and field environments. Similar results were presented by Busch et al. (2014) who compared a real laboratory environment with a virtual field environment in terms of usability and learnability. They used the SUS questionnaire and showed no significant differences between the environments. This is in line with Patel and Nichols (2004) who reported quite similar usability scores for different VR-systems. All of the aforementioned studies report no differences in usability between the environments; however, no comparisons are made to a real field environment.

In contrast, Duh and Chen (2006) detected significantly more usability problems and longer task performance times in the field environment compared to the laboratory environment. Additionally, participants in the field conditions showed more negative behavior. Sun and May (2013) also detected more negative behavior in the field setting, but no significant differences in the number of usability problems between the field and laboratory environments. In contrast to these a study on mobile systems comparing the laboratory and field by Kjeldskov et al. (2004) reported significantly more usability problems in the laboratory. Furthermore, they divided them into three categories: critical, serious and cosmetic problems. There were no significant differences in critical problems, but significant differences in serious and cosmetic problems between the conditions were evident.

The presented overview of studies shows inconsistent findings concerning the kind of environments, the evaluation techniques and the factors that were examined. Therefore, more research is necessary to give meaningful statements on the influence of different environments on presence and their relationship to usability and user experience.

3. Experimental method

3.1. Research questions and hypotheses

The discussed related studies clearly demonstrate the need to examine presence, usability and user experience in VR in comparison to a real field environment, as this has not been done before. We compared two kinds of field environments (real and virtual) and investigated whether significant effects on reported presence, usability and user experience were evident (H1). We used a mobile navigation application as the evaluation scenario. Table 2 gives a detailed overview of the used environment, technical setup and dependent variables.

In addition we wanted to investigate whether the reported presence has a significant influence on the reported user experience and usability (H2, H3). We therefore expected the following scenarios:

H1: The environment will significantly affect presence.

Based on previous work (Busch et al., 2014; Nisenfeld, 2003; Usoh et al., 2000), it is expected that the presence factors, sense of physical space, engagement, and ecological validity will be significantly higher in the real field environment, while negative effects will be significantly higher in the virtual field environment.

H2: The real field experiment will offer a higher usability rating than the virtual field environment.

Supported by previous studies that show a lower performance (de Kort et al., 2003) and more negative effects in a virtual environment (Busch et al., 2014; Toet and van Schaik, 2012), we expect that a real field environment will generate a higher usability. Based on earlier work (Busch et al., 2014), where some presence factors and the SUS were associated, we expect that there will be a positive association between presence factors and the SUS.

H3: The real field experiment will offer a higher user experience rating

Table 2
Overview of environments, setup and variables.

	Virtual	Real
Environment	Field environment	
Technical setup	Five-side CAVE	Real city
Dependent variables	Subjective presence of environment Usability and user experience of a mobile application	

than the virtual field environment.

As we expect differences in presence in the two environments and more negative effects in the virtual field environments, we expect different results in the user experience too. We hypothesize significant positive associations between presence factors and the user experience in both environments.

Finally, once these hypotheses have been verified, we aimed to identify the influencing factors on usability and user experience that occur in virtual field environments compared to real field environments. This shall allow others who are conducting usability and user experience studies in virtual field environments to assess the correctness of their findings. We want to increase the confidence in their found results by identifying the factors that may bias their findings and therefore helping them prevent false conclusions.

3.2. Setup and mechanics of the study

The hypotheses were tested in a between-subject study with the environment as the independent variable (Brade et al., 2016). Participants were randomly assigned to one of two groups where they had to complete specific tasks in either a real field environment or a virtual field environment. Eleven dependent variables were recorded: four presence factors (sense of physical space, engagement, ecological validity and negative effects), measured with the ITC-SOPI questionnaire, together with seven user experience factors (attractiveness, perspicuity, efficiency, dependability, stimulation and novelty) measured with the User Experience Questionnaire (UEQ) (Laugwitz et al., 2008), and usability measured with the SUS. We used the same questionnaires in both environments to ensure comparability, and to obtain baseline data for presence in reality, as some participants might get sick from looking at the mobile whilst walking, that would reflect in higher negative effect.

The study itself consisted of three parts (Brade et al., 2016): pre-assessment, main study and post-assessment. In the pre-assessment, we collected demographic variables (age, gender and education) as well as a self-assessment of the participant's own sense of orientation and spatial ability. The main study comprised a geocaching game with a smartphone application in the real or virtual city center of Chemnitz, Germany. All users had to solve the same seven tasks in the same order. Afterwards, we assessed the dependent variables in the post-assessment with post-test questionnaires, where the participants were asked to only rate the used geocaching application and not the system as a whole. All participants received financial compensation (5 €) or course credits for their participation.

To reduce unsystematic variances in the performance of the study we used a study protocol that exactly defined the proceedings. In this protocol we noted all deviations and remarks the participants made while they were completing the tasks and registered confounding variables in the real field study.

3.3. Geocaching game in both environments

In the main part of the study the participants had to play a geocaching game using a smartphone (Google Nexus) which guided them through the real or the virtual city center of Chemnitz, Germany. To program the game we used the Actionbound app from Zwick and Rauprich (2016). This app is designed to create individual city rallies or scavenger hunts for smartphones and tablets, for discovering a city or other places. They are created using a web interface and then shared with others via a Quick Response (QR) Code or the app integrated public tour collection. The Actionbound app offers a variety of different game elements like maps, a compass, pictures, videos quizzes or QR codes. Our geocaching game consisted of seven places that the users had to visit over a total distance of 1.7 km. To track the participant's position, the Global Positioning System (GPS) signal of the smartphone was used, comparing the coordinates of the sought location with the participant's position for every location. A map (left part of Fig. 1) displaying the city center, the present position and the location of the next place was used for navigation. Upon arrival at the next place the participants saw a confirmation message (middle part of Fig. 1) and the coordinates of the following place were unlocked (right part of Fig. 1) (Brade et al., 2016). This procedure, pictured in Fig. 1 was the same for every location.

In the virtual field environment we made use of the functionalities of the VR software instantreality developed by the Fraunhofer-IGD (2016) to simulate the GPS signal for the Actionbound app. These GPS coordinates were then transmitted to the Fake GPS Location app (Lexa, 2016) which forwarded them via an android debug bridge port to the Google Nexus smartphone.

3.4. Independent variables: virtual versus real field environment

3.4.1. CAVE

To compare the real field environment with a highly immersive virtual field environment we decided to conduct the study in a CAVE (see left part of Fig. 2 and left part of Fig. 3). Slater and Wilbur (1997) documented that the level of immersion that a person experiences in a VR environment has a major influence on the reported presence. A highly immersive CAVE is therefore the preferred option for our study. The CAVE we used is located at Technische Universität Chemnitz. This five-sided CAVE, with an edge length of three meters, is based on the principles described by Cruz-Neira et al. (Cruz-Neira et al., 1993, 1992). Passive circular polarization is used to achieve stereoscopic vision. The images are computed by a cluster of 10 computers that are equipped with NVidia Quadro 6000 graphic cards. One additional control computer manages the synchronization of the cluster. The images for each side of the CAVE are displayed using rear-projection of 20 full HD projectors with passive polarization. One pair of projectors displays the upper half-image and a second pair displays the lower half-image. Edge blending is applied to adjust the light intensity in the overlapping areas. In order to track the position of the user inside the CAVE we used a passive optical infrared tracking system by ART with six cameras. The static virtual model of the city center of Chemnitz, Germany resulted from an architectural project. The model contained no sound.

All interactions with the virtual field environment were performed using gesture based navigation and the simulated GPS tracking of the smartphone. The gesture based navigation was implemented using the Microsoft Kinect system, developed by Lorenz et al. (2015). It allows the user to navigate through the virtual world in a standing position without having to wear additional devices. The gestures used for navigation are intended to come as close to natural walking as possible. To move forward the participants have to put the right foot in front, to move backwards they have to set it back. For rotation they have to turn their shoulders into the direction they want to turn; moving forward/backward and turning can be done simultaneously. After a short demonstration by the experimenter, the participants adopted the movements quickly.

3.4.2. Real field environment

The study in the real field environment was held in the city center of Chemnitz, Germany (see right part of Fig. 2 and right part of Fig. 3) In contrast to the virtual field environment, participants completed the geocaching game in the real field environment without the physical presence of the experimenter. Having the experimenter following the participants might have influenced how they behave and would therefore be a severe cofounder. In case of problems, the participants could call the experimenter and solve them by phone.

In the following sections we use the term **CAVE** for the virtual field environment and **real city** for the real field environment.

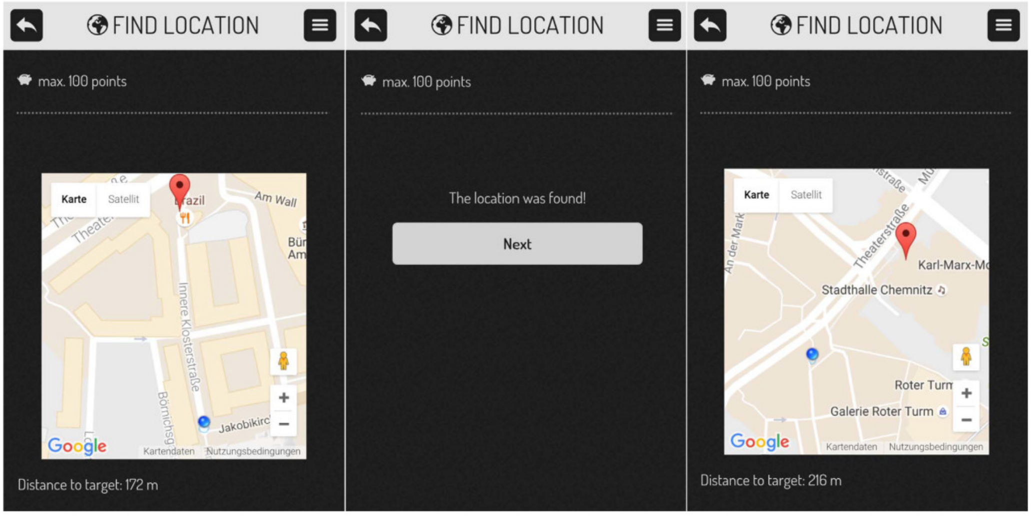

Fig. 1. Location 3 and 4 of the geocaching game.

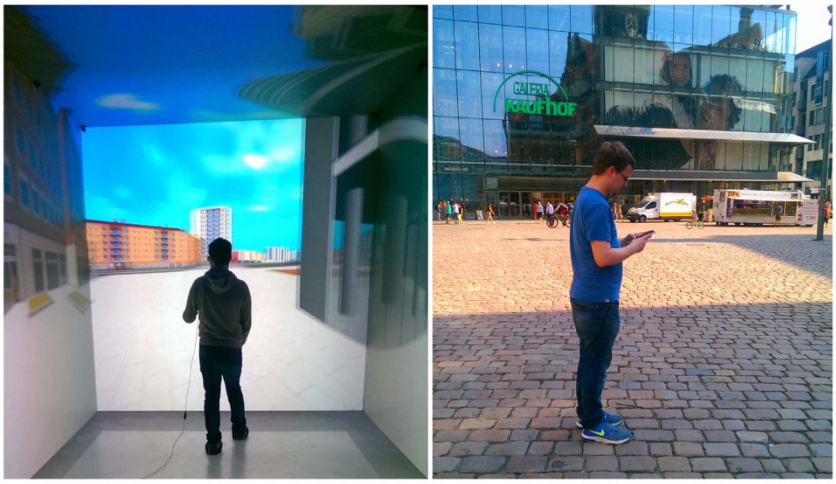

Fig. 2. Participant in the virtual field environment – CAVE (left) and in the real field environment (right).

Fig. 3. The shopping center Galerie Roter Turm in the virtual field environment (left) and in the real field environment (right).

3.5. Dependent variables: presence, user experience and usability

In both environments we measured the dependent variables: presence, user experience and usability.

3.5.1. Presence

We assessed the perceived presence with a shortened version of the ITC-SOPI (Lessister et al., 2001), which included only 12 instead of 44 items. The four factors, sense of physical space, engagement, ecological validity and negative effects were measured by the three top loading items per scale.

- *Sense of physical space:* indicates "a sense of physical placement in the mediated environment, and interaction with and control over parts of the mediated environment" (Lessister et al., 2001).
- *Engagement:* includes the "user's involvement and interest in the content of the displayed environment, and their general enjoyment of the media experience" (Lessister et al., 2001).
- *Ecological validity:* evinces the believability and the realism of the content as well as the naturalness of the environment (Lessister et al., 2001).
- *Negative effects*: summarizes "adverse physiological reactions" (Mania and Chalmers, 2004) e.g. motion sickness, dizziness of virtual environments.

The participants were asked to rate on a five-point Likert scale.

3.5.2. User Experience

One of the best validated questionnaires for assessing user experience is the UEQ by Laugwitz et al. (2008), which is why we choose it for our study. The UEQ contains 26 bipolar items divided into the following 6 scales:

- *Attractiveness***:** characterizes the participants general impression towards the product
- *Perspicuity:* describes how difficult it is to understand how to use the product
- *Efficiency:* outlines the ability to use the product fast and efficiently
- *Dependability:* addresses the feeling of having control over the system
- *Stimulation:* describes how interesting and exciting the product is for the user
- *Novelty:* evaluates the products innovation and creativity

Besides attractiveness as a pure stance dimension, the scales are addressing two kinds of quality perception – pragmatic and hedonic quality. Pragmatic quality, described by the factors perspicuity, efficiency, and dependability, covers task-oriented quality aspects – typically usability factors as described above. In contrast, hedonic quality is characterized by the factors stimulation and novelty. Attractiveness is described by non-task oriented quality aspects, which should evoke emotion and a relationship to the product. The scales were assessed by a seven-point semantic differential.

3.5.3. Usability

The ten-item SUS (Brooke, 1996) was used to measure the perceived usability of the system. The rating of each statement was made on a five-point Likert scale.

3.6. Statistical methods

To evaluate the questionnaires we used non-parametric methods for the significance tests and the correlations. We conducted a Mann-Whitney test (unpaired two sample test) with the Monte Carlo method and present the one-tailed significance values (as our hypotheses are directed) in the result section. For the connection between the dependent variables Spearmans correlations were calculated. In both significance tests and correlations, the statistical significance was set at $p < 0.05$. Cohen's conventions were used to interpret size effect (r) for significant effects and correlations. A value of ± 0.10 represents a small effect, a value over ± 0.30 a medium effect and a value over ± 0.50 a large effect.

Beside the named dependent variables, we also collect data of the spatial ability, because it is important for the navigation task. Therefore we used the cube perspective test by Stumpf and Fay (1983), to determine if the spatial ability has an influence on the dependent variables. The data of the participants spatial ability was collected with an online application during the pre-assessment.

3.7. Sample

We analyzed the data of 60 participants, 31 participants in the virtual field environment and 29 participants in the real field environment. The sample mainly contained students of the Technische Universität Chemnitz (76.7%). In the CAVE condition 58.1% and in the real field environment 62.1% of the participants were female, and both groups had similar mean participant age (CAVE: 25.5 (SD=7.18); real city: 25.7 (SD=4.22)). Fig. 4 compares the participants' particulars between environments concerning self-assessment of their own sense of orientation and the variation in their previous experience with virtual reality systems (Powerwall, HMD, CAVE) and geocaching games.

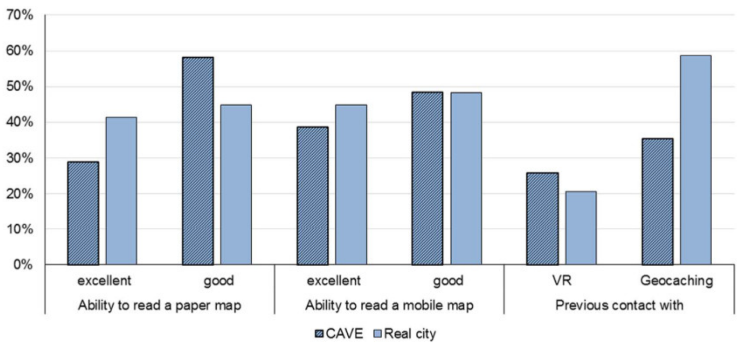

Fig. 4. Results of the self-assessment of participants' own sense of orientation and the variation in their previous experiences with virtual reality systems and geocaching games.

4. Results

In this section we present all the results from the study to later interpret them from the psychological viewpoint. The parts of the results relevant for the discussion of industrial/ergonomic impact were reported in a condensed form in (Brade et al., 2016).

4.1. Psychometric properties of the scales

The internal consistency of the psychometric scales was measured using Cronbach's alpha (CA) where a score over 0.7 indicated an acceptable internal consistency of the scale. The CA values for the scales of the ITC-SPOI, UEQ and SUS are listed in Table 3.

The CA values for nine of the 11 scales are higher or close to 0.7 and can therefore be seen as sufficient. The scales of efficiency and dependability (See Table 3) show a low CA value of 0.42 and 0.47. This may be explained by misinterpretation of the scales by the participants. Such interpretational problems are already reported as a possible reason for a small CA (Rauschenberger et al., 2013). Both scales will be used for further data analysis, but are to be interpreted with caution.

4.2. Effects of Sample Characteristics

To identify the influence of the spatial ability on the dependent variables we compared the results of the cube perspective test between the environments and calculated correlations of the spatial ability and the dependent variables: A pair-wise comparison between the CAVE and the real field environment showed no significant differences between the environments [U=435.5, p=0.42]. There was also no significant correlation between the results of the cube perspective tests and the presence factors, or the user experience factors. The association between the spatial ability and the usability was not significant in the real field environment, but there was a positive correlation for these factors in the CAVE (r=0.37). The influence of the spatial ability is therefore not notable and may be disregarded.

4.3. Differences in presence between the environments

Table 4 presents the means, standard deviations and medians (gray) of the four presence factors in each environment. Fig. 5 shows the means of the presence factors as bar charts. In the CAVE the means of engagement and negative effects are higher, whereas the means of sense of physical space and ecological validity are higher in the real field environment.

Significant differences between 3 of the 4 presence factors in the environments could be found. There were significant differences in the engagement scale [U=306.5, p=0.016, r=−0.28], the ecological validity scale [U=261.0, p=0.002, r=−0.36] and the negative effects scale [U=163.0, p=0.000, r=−0.56], but not for the sense of physical space scale [U=367.0, p=0.11].

Table 3
Cronbach's alpha measures for the ITC-SOPI, SUS and UEQ psychometric scales.

	Scale	CA
ITC-SOPI	Sense of physical Space	0.71
	Engagement	0.79
	Ecological validity	0.67
	Negative effects	0.62
SUS	Usability	0.62
UEQ	Attractiveness	0.87
	Perspicuity	0.64
	Efficiency	0.42
	Dependability	0.47
	Stimulation	0.79
	Novelty	0.85

Table 4
Means, (standard deviations) and medians (in gray) of the presence scales (rated from 1 to 5) for the two environments.

	CAVE	Real city
Sense of physical space	3.34 (0.89)	3.69 (0.85)
	3.67	3.67
Engagement	4.15 (0.73)	3.72 (0.87)
	4.33	4.00
Ecological validity	3.35 (0.69)	3.91 (0.91)
	3.33	4.00
Negative effects	2.09 (0.86)	1.24 (0.38)
	1.67	1.00

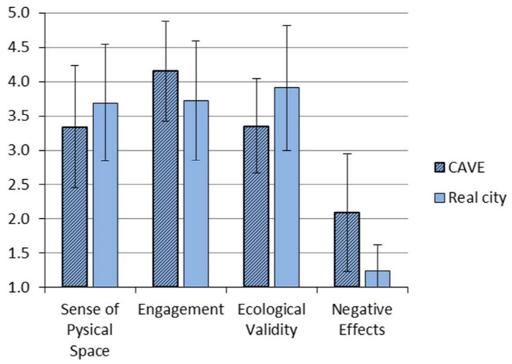

Fig. 5. bar charts of the means of the presence factors (rated from 1 to 5) for the two environments with error bars showing standard deviations.

Table 5
Means, standard deviations (white) and medians (gray) of the SUS scale in %for the two environments.

	CAVE	Real city
Usability	82.98 (9.23)	89.57 (5.43)
	85.00	90.00

4.4. Differences in usability between the environments

In Table 5 the means, standard deviations and the medians (gray) for the factor usability in both environments are shown. Based on the interpretation of the SUS score by Bangor et al. (2009) our usability results range from good (CAVE) to excellent (real city). A pair-wise comparison between CAVE and the real field environment shows significant differences in usability [U=254.5, p=0.001, r=−0.37].

4.5. Differences in user experience between the environments

Table 6 presents the means, standard deviations and the medians (gray) with the means of the user experience factors presented in Fig. 6. The means of the attractiveness, efficiency, stimulation and novelty scales are higher in the CAVE. On the other hand, the means of the perspicuity and dependability scales are higher in the real field environment.

There were significant deviations between the environments concerning the dependability [U=201.5, p=0.00, r=−0.48], novelty [U=144.5, p < 0.000, r=−0.58] (higher in CAVE) and stimulation [U=272.0, p=0.005, r=−0.34] (higher in the real city). The test shows

Table 6
Means, (standard deviations) and medians (gray) of the UEQ scales (rated from −3 (low) to 3 (high)) for the two environments.

	CAVE	Real city
Attractiveness	1.73 (0.75)	1.46 (0.03)
	1.67	1.67
Perspicuity	2.01 (0.66)	2.21 (0.79)
	2.00	2.50
Efficiency	1.28 (0.61)	1.07 (0.81)
	1.25	1.00
Dependability	1.05 (0.76)	1.79 (0.68)
	1.00	1.75
Stimulation	1.82 (0.91)	1.12 (0.89)
	2.00	1.50
Novelty	1.62 (0.86)	0.16 (1.15)
	1.50	0.00

no significant differences for the three remaining scales: attractiveness [U=386.5, p=0.174], perspicuity [U=359.0, p=0.088] and efficiency [U=382.5, p=0.157].

4.6. *Influence of presence on usability and user experience*

To find out if the presence factors were associated with the usability and the user experience factors, the correlations, shown in Table 7 and Table 8 were calculated. Overall there were more significant correlations in the CAVE than in the real field environment. In both environments attractiveness was associated with sense of physical space (sense), engagement (eng) and ecological validity (eco). Furthermore, stimulation and engagement were significantly correlated, in both environments. For the negative effects (neg) scale there were two significant correlations for the virtual environment but only one for the real environment.

The association between usability and the presence factors, showed low and insignificant findings in the real field environment. However, all presence factors correlate significantly with usability in the CAVE. The higher the sense of physical space, engagement and the ecological validity, the higher the participants rate the usability of the system. The scales of negative effects and usability show a negative association, so that the lower the negative effects, the higher the reported usability.

Table 7
Spearmans correlations of the UEQ-factors and the SUS with the presence factors for the virtual field environment (significant correlations are made bold).

	Sense	Eng	Eco	Neg
Attractiveness	**0.65**	**0.84**	**0.61**	−0.14
Perspicuity	**0.32**	**0.42**	**0.49**	**−0.36**
Efficiency	**0.44**	**0.46**	**0.32**	−0.11
Dependability	**0.32**	0.28	**0.65**	**−0.49**
Stimulation	**0.49**	**0.46**	**0.45**	−0.09
Novelty	**0.42**	**0.31**	0.28	0.20
Usability	**0.36**	**0.53**	**0.42**	**−0.50**

Table 8
Spearman's correlations of the UEQ-factors and the SUS with the presence factors for the real field environment (significant correlations are made bold).

	Sense	Eng	Eco	Neg
Attractiveness	**0.49**	**0.67**	**0.37**	0.26
Perspicuity	0.23	−0.12	0.25	−0.18
Efficiency	0.13	0.28	−0.01	0.10
Dependability	0.25	−0.04	−0.03	0.11
Stimulation	0.23	**0.63**	0.25	**0.33**
Novelty	0.28	**0.57**	0.19	0.20
Usability	0.10	0.19	0.07	0.20

4.7. *Presence in virtual and real field environments compared to real laboratory environment*

In addition to the comparison between the virtual and the real field environments concerning the perceived presence, we compared the results with the findings of Busch et al. (2014).

Fig. 7 shows the results of both studies in terms of presence. Both virtual environments are very similar at all four presence scales furthermore the two real environments have quite similar results. In addition, the differences named in Section 4.3 are in line with the comparison of virtual and laboratory environments.

4.8. *Duration of task completion*

The time to complete the geocaching task differed between the real and the virtual field environment. On average, the geocaching game in the virtual field environment lasted for 14 min and in the real field environment for 20 min. This difference can be explained by the maximum speed in the CAVE. The maximum speed of movement in the virtual environment is comparable with going jogging. The majority

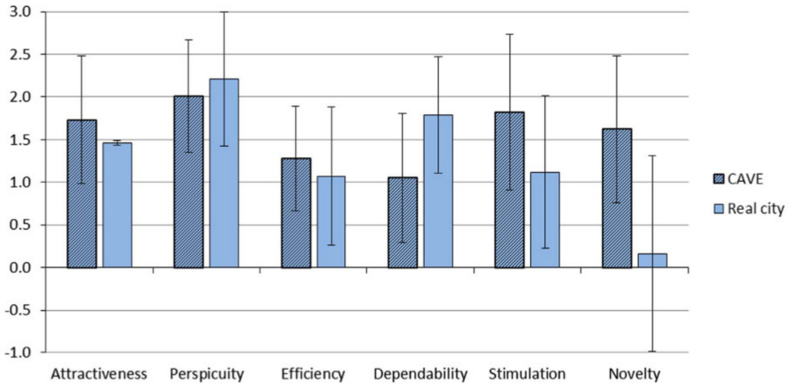

Fig. 6. bar charts of the means of the UEQ factors (rated from −3 (low) to 3 (high)) for the two conditions with error bars showing standard deviations.

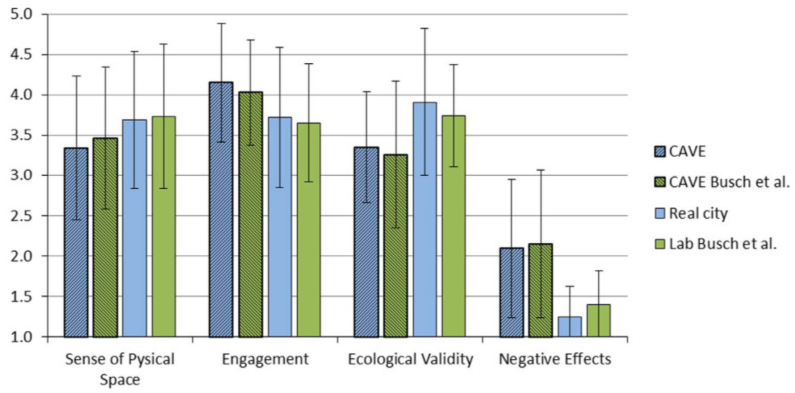

Fig. 7. Comparison of the presence results of the presented study and the study by Busch et al. (2014) showing the means and the standard deviations as error bars.

of the participants moved with almost maximum speed through the virtual city center, whereas the participants in the real city center preferred a slower speed in general.

5. Discussion

5.1. Summary of the study and important findings

In this study we analyzed the difference in effects of virtual and real field environments on presence, and the possible consequences for the self-reported user experience and usability. Our results show significantly higher values on the engagement and the negative effects scale for the CAVE, in contrast to the real field environment with a higher ecological validity. We are confirming previous work (Busch et al., 2014) that showed the same results or partially similar findings (Mania, 2001; Mania and Chalmers, 2004; Nisenfeld, 2003; Usoh et al., 2000). Our hypothesis H1 was supported; only the results of the engagement scale differed from our expectations where we received a higher value for the virtual field environment.

Our hypothesis H2 was fully approved as we measured significantly higher values in the real field environment. For the first time we could verify a significant correlation between the environment and usability that previous studies did not examine (Busch et al., 2014).

Hypothesis H3 was approved for the dependability as we can report higher measures for the real field environment, although this statement is limited due to the low CA value. Because we expected that the higher negative effect values in the virtual environment affect the perceived hedonic quality negatively, it is surprisingly, that we found higher values for the stimulation and novelty factors for virtual field environment. That means, that even when the negative effects are high, the hedonic quality is not impaired. For the other three scales: attractiveness, perspicuity and efficiency equal results can be reported. The analysis of the correlation between the presence factors and the user experience factors could verify a significant dependability of 18 of 24 combinations in the virtual field environment but only for 6 of 24 in the real field environment. Our results also verify the measures of previous studies (Patel and Nichols, 2004; Sylaiou et al., 2010) for a connection between presence and enjoyment of a virtual environment.

5.2. Interpreting the results of this experiment

If we want to use virtual environments to assess new products like mobile applications, their fundamental principles have to be evaluated. This is important to make sure that they really can replace real environments and the results of product evaluations in a virtual field environment are the same.

The higher negative effects we found in our presence evaluation confirms the current state of knowledge as effects like simulator sickness are well known and are therefore expected. The most interesting result of our presence evaluation is the differences in the engagement scale which is in contrast to the findings of Nisenfeld (2003), but in line with the results of Busch et al. (2014). This could imply that the CAVE used in this study and in the study of Busch et al. (2014) provided a higher immersion then the HMD setup of Nisenfeld (2003) and therefore leading to a more engaging experience. This implication should be verified in a future study with VR systems providing different levels of immersion. The confirmation of our results together with that of Busch et al. (2014) are very important for future studies as it shows that a highly immersive CAVE produces higher engagement values, which implies a higher psychological involvement and a higher user enjoyment. Neglecting this point of view when evaluating products in a virtual environment may lead to flawed results, because the positive or negative experience of the virtual environment may influence the participant's ratings.

The differences in the task completion time resulted from the maximum navigation speed in the CAVE that most participants preferred to move with, which is comparable to jogging. We think that there are two possible reasons why the participants choose to 'jog' in the virtual field environment but not in the real one. The first reason is, that going faster in the CAVE is not correlated with increased physical effort as in the real world. Secondly, it might be possible that the participants were not aware of the high speed they moved within the virtual world. However, this is not supported by the results for the presence factor of physical space where no differences between the real and virtual environment were found. Although we know that different locomotion methods induce a different presence (Lorenz et al., 2015) we did not assess the presence of the navigation method separately. Previous investigations (Guy et al., 2015; Lorenz et al., 2015) have already shown that the utilized navigation method is associated with a high presence and an easy, comfortable usage. Furthermore, we wanted to assess the presence of the entire high immersive virtual field environment setup. The influence of the navigation method is therefore included in the presence measurements of the whole system.

Another important result is the comparison of the measures of the ITC-SOPI for the real lab environment by Busch et al. (2014) and our real field environment. For all presence factors they show similar values for both real environments. This implies that both kinds of real environments (lab and field) are comparable concerning presence. These results suggest that either of the real environments would be suitable for this type of comparative study between virtual and real environments.

For usability we measured different results to Busch et al. (2014). In contrast to them we found significant differences for usability in the virtual field environment and the real field environment. One interpretation could be that a laboratory environment as used by Busch et al. (2014) and a virtual field environment are more similar than a real field environment and a virtual field environment in terms of usability. Another interpretation could be that the tasks the participants had to perform in our study were better suited for testing in a virtual field environment with the given technical setup and scenario. It could be speculated that our open world scenario using long established technology (GPS, geocaching) led to certain expectations on how the geocaching game should behave, so occurring problems had a stronger negative effect when the usability was rated. In contrast to this Busch et al. (2014) used an indoor internet of things scenario where the participants had to interact with novel, partly non-existing devices inside buildings. As the interaction with these new technologies is unfamiliar for most of the users they might expect more problems in the functioning of the technology and their tolerance towards failures might be higher, therefore influencing their rating of the usability. This might even affect how the participants tolerated the difference between the artificial navigation method in the virtual environment and natural walking in reality. However all of these aspects have yet to be examined in a future study.

As our study is the first one investigating user experience and how it is influenced by presence in a virtual and real field environment, there are few studies to compare our results to. Albrecht et al. (2013) researched user experience in an AR environment and documented significantly higher values for its hedonic quality. Our results verify these data as we also observed significantly higher scales for the hedonic factors stimulation and novelty in the virtual condition. Nonetheless, these comparisons must be made with caution, as AR and VR environments are different.

We could also verify a significantly higher dependability of the geocaching game in the real field environment, which indicates a higher pragmatic quality. As this result corresponds with the measures for the usability scale, we think that this statement is valid, despite the medium CA value of the dependability.

Concerning the connection of presence and UEQ factors, we found a medium correlation between presence and hedonic quality in the virtual field environment. This supports the findings of Patel and Nichols (2004) and Sylaiou et al. (2010) who have both documented a positive correlation between presence and enjoyment. When looking at each presence factor and its effect on the UEQ factors in both environments, there is a high correlation with the engagement scale. This means that the enjoyment of the experience is important for the user and independent of the environment, despite the slightly higher correlation with the virtual field environment. When comparing the other three presence factors we also found high correlation between the sense of physical space and ecological validity, and the UEQ factors, with a surprisingly low correlation with the negative effects. This is in contrast to the results for the real field environment where almost no significant correlations were measured. For assessing a product in a solely virtual field environment it is therefore important to reach a high presence of the user. We advise using a highly immersive VR system with a sound evaluation scenario and realistic virtual model to assure this. Otherwise evaluation results with only a low confidence in their correctness can be achieved.

One additional remark for the especially high values for the engagement scale is that due to the novelty of VR scenarios, most participants just enjoyed participating in VR. This positive feeling could influence the assessment of a product and should always be considered when only a virtual scenario is chosen for the evaluation. This effect could be offset by using a corrective factor which will need to be determined through future study. However, as VR is hitting the consumer market it is likely that people will get used to being in a virtual world so that this enjoyment factor might not be as relevant in the future. To confirm this assumption, replication of this study in a few years when VR has become an everyday experience might be very relevant.

One additional possibility to compare the real with the virtual environment would have been to use physiological signals (e.g. pulse, skin conductivity) to assess presence. Meehan (2001) performed such experiments but only for different VR scenarios (exciting vs. non-exciting). We decided against the inclusion of a physiological assessment for methodological and practical reasons. The means of locomotion in our scenario differs in the way it physically stresses the body (normal walking vs. slight movements whilst standing). Because of this difference the gathered data could not be compared between the conditions. We also would have to follow the participants in the real word scenario to note non-tasks related events. We think that following them would have changed the way they behave and perform the task. Also the technical set up for collecting physiological data would severely increase the effort preparing and conducting the experiment. In a future study it might be interesting to collect physiological data in a VR scenario and compare this with data from questionnaires, to see if there are links between the physical reaction and the psychological impression.

6. Conclusion

The current study shows that a virtual field environment is a tangible alternative to a real field environment when performing studies for evaluating products, if the influence of presence is considered, as it affects the user ratings for usability and user experience. A highly immersive virtual field environment with a realistic virtual model and a sound simulation of reality, provide the bases for reliable results of product evaluation. Virtual field environments are a good choice for assessing usability and user experience studies especially due to the controllability of confounding variables and the possibility of assessing early virtual prototypes of products. However, virtual and real field environments slightly differ in perceived presence, making improvements of the virtual environment necessary. The higher value for ecological validity in the real field environment demonstrates the need to improve the realism of virtual models and the stronger involvement of other senses like sound, touch or smell. Therefore, the achievement of a high ecological validity could become a quality goal for studies performed in a virtual environment giving confidence in the found results.

Besides the integration of further senses, the improvement of interaction techniques (i.e. for navigation) and an increased realism of the virtual model could also lead to increased presence. Our study shows the importance of keeping negative effects low, so that small problems with the technical setup do not influence the assessment of the independent variables. This is especially important for user experience evaluations in a virtual environment where all of these aspects have to be considered in order to obtain reliable results.

Holistic approaches combining real and virtual settings should also be considered. Future studies will need to investigate how the benefits of both kinds of environments can be combined together to create a realistic and controllable system. Using an AR environment where the assessed product is virtually blended into reality might prove as an ideal combination. However, in this case, the effect of the gap in realism between the virtual and real objects in terms of presence and their relation to usability and user experience needs to be investigated.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijhcs.2017.01.004.

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Presence and User Experience in a Virtual Environment under the Influence of Ethanol: An Explorative Study

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Virtual Reality (VR) is used for a variety of applications ranging from entertainment to psychological medicine. VR has been demonstrated to influence higher order cognitive functions and cortical plasticity, with implications on phobia and stroke treatment. An integral part for successful VR is a high sense of presence – a feeling of 'being there' in the virtual scenario. The underlying cognitive and perceptive functions causing presence in VR scenarios are however not completely known. It is evident that the brain function is influenced by drugs, such as ethanol, potentially confounding cortical plasticity, also in VR. As ethanol is ubiquitous and forms part of daily life, understanding the effects of ethanol on presence and user experience, the attitudes and emotions about using VR applications, is important. This exploratory study aims at contributing towards an understanding of how low-dose ethanol intake influences presence, user experience and their relationship in a validated VR context. It was found that low-level ethanol consumption did influence presence and user experience, but on a minimal level. In contrast, correlations between presence and user experience were strongly influenced by low-dose ethanol. Ethanol consumption may consequently alter cognitive and perceptive functions related to the connections between presence and user experience.

Virtual Reality (VR) has been used for a variety of applications for the last few decades, ranging from entertainment via medical applications to industrial use. In the biomedical context, VR is applied to treat different types of mental health disorders e.g. fear of spiders, heights, public speaking, schizophrenia or substance disorders[1,2]. VR is also applied successfully in the rehabilitation of stroke patients[3] or for the treatment of post-traumatic stress disorders (PTSD)[4]. Positive effects in patient treatment have been demonstrated[3–5], proving VR to be capable of successfully influencing behavior on a subconscious level. Associated with the experience of a virtual scenario as being real is a high sense of presence[6] – the feeling of 'being there'.

According to Slater and Wilbur, there are basically two main pillars to support presence, context and immersion[6]. Context indicates how convincing the setting and the storytelling of the virtual scenario are for the user. Immersion focusses on the technical aspects to provide sufficient sensory information for the perception system, e.g. good stereoscopic imaging with high resolution images and an appropriate framerate[7].

In general, user experience is important for all applications as it describes 'a person's perceptions and responses that result from the use and/or the anticipated use of a product, system or service'[8]. A good user experience enables the user to quickly learn how an application is operated, to operate it efficiently and to 'enjoy' the use of the application. Therefore, user experience is a measure of the user's willingness to utilize a VR application and their

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emotional connection with it[9]. This is an important aspect for all applications, e.g. for the above-mentioned applications in the biomedical and psychological domains, as in our case. In a medical context, the importance of a good user experience may be exemplified by the way in which patients adapt to VR applications, and the underlying motivation, which could be partially driven by the joy of using such applications, quickly submerging into it.

The rationale for a high presence to be desired for most VR application is that the user should behave and react the same way in the virtual scenario as in reality. The user's feeling to be present in a virtual scenario forms the basis for almost all VR applications, as it enables them to be involved. VR applications for the treatment of phobias[2] is one example. However, in more research areas, VR is used in studies as a test environment, because it can provide a higher ecological validity (realism) than a laboratory environment, whilst at the same time it allows for a higher control than in a real environment, e.g. to assess the user experience of a product in an early phase of development[10–14]. The basic assumption of such studies is often that the participants would behave and react in the same way as in a real situation. However, this assumption is corrupted, as we demonstrated that presence has an influence on user experience (Brade *et al.*[15], Busch *et al.*[16]). In an earlier work on VR[15] we could show that presence, user experience and usability were significantly different between the real world and the VR measurements. Furthermore we could show a strong connection between presence with user experience and usability in the VR environment, which was absent in the real world.

Both presence and user experience are connected to perception, cognition and emotion. The first step to achieve presence in a VR scenario is to allow the users to perceive the computer generated virtual world via their perceptional system. This artificial sensory input has to be cognitively processed by the brain. Depending on the quality of the sensory input and its cognitive processing, a weaker or stronger feeling of 'being there' in the VR scenario by the users is achieved. This results in a perceived degree of presence. The engagement of users in a VR scenario can trigger any emotion depending on the content, e.g. fear as in VR phobia treatment applications[2]. However, the sole factor of being present in VR can trigger emotions like excitement or even discomfort resulting from negative effects, such as cybersickness[17].

However, the exact understanding of the term 'presence' and processes of perception and cognition, which lead to the formation of presence, are debated since the early 1990s. Coelho *et al.*[18] summarized the different interpretations and categorized them into media-presence, as a result caused by technology to be in VR, and inner presence, the general feeling of being present e.g. in reality, dreams, books, movies, VR etc[18]. This separation has also prevailed in recent research described by Diemer *et al.*[19]. Further, Slater[20] stated that presence is actually binary (present or not present) and should not be mixed with emotions and involvement[20,21]. However, existing presence questionnaires often reflect that separation by providing scales for spatial presence and involvement, but are still considering all scales as presence[22–24]. Most literature does not follow Slater's[20] harsh separation and implicitly argues for a tight interrelations of presence, involvement and emotion[18,19]. We also follow the view of Coelhos *et al.*[18] on inner presence as "an experience common among different types of human experiences independent of any technology" a "neuro psychological phenomenon"[18]. To emphasize this, Coelho *et al.*[18] relate to the work of Loomis[25] who considers a synthetic experience, like in VR, in line with the normal every day experience of the real world. The world as we perceive it, results from our senses and nervous system interacting with the physical world[25]. Moreover "the physical world, including our nervous system, is not given to us directly through experience but is inferred through observation and critical reasoning"[25]. Also the more recent research conducted by Seth *et al.*[26] argues in this direction as they consider presence "a basic property of normal conscious experience", occurring constantly. Seth *et al.*[26] provide the example of schizophrenia and depersonalization disorder for a disturbance in presence in normal reality[26]. Following this theory, in VR, the initial sensory input is mediated by technology but once perceived by our senses undergoes the same interpretation mechanism. Coelho *et al.*[18] further note that the perceived control over a VR experience, and the possibility to interact, can lead to the user forgetting the technology and being present. The extent of control and the quality of the sensory input created by technology (immersion) can then lead to a different degree of feeling present in VR[18,27]. This important role that immersion plays in the creation of presence is further investigated by Diemer *et al.*[19], but they also emphasize the importance of emotion for the creation of presence. They rest on the theory of Seth *et al.*[26] who postulate that presence, in general always, results from the mismatch of the actual current emotional state of an individual and a predicted emotional state resulting from experience. In terms of VR this is the essential suspension of disbelief, necessary for an individual to feel present in a VR scenario, despite knowing that it is located in a different place in the real world. Following this direction, and evaluating different research regarding the effect of emotions on presence, Diemer *et al.*[19] developed an interoceptive attribution model of presence[19]. According to that model the reported presence of individuals through presence questionnaires is the result of a cognitive judgment from the immersiveness, the interactivity provided by the VR system and the emotional arousal from the perceived content of the VR scenario[19]. The described functions that the sensory input (immersion) and emotion play in the formation of presence in the real world and in VR are in line with the different presence findings in our previous study[15]. There, the differences in the evoked emotions and the sensory input between the real world and the virtual environment could explain the difference in presence.

The connection of user experience with perception, cognition and emotion may be more obvious. An application must stimulate the sensory cues of the users so that they can use it. The process of learning how to use an application is a cognitive task. The experience of the application will lead to an emotional attitude of the users towards it. Our previous studies further suggest that there is a connection between presence and user experience[15,16].

Human perception, cognition and emotion can be influenced by drugs such as ethanol, codeine, amphetamines, tranquilizers or other similar substances, which could potentially be confounders. Ethanol may influence perception of contrasts, cause blurry vision, decision making, ease trust in others and affect emotion[28–32].

These effects are well studied in the context of drunk driving studies. VR is commonly applied as a setting for such studies, instead of real and potentially dangerous driving scenarios. However, most VR drunk driving studies failed to assess presence and the influence of ethanol, which may negatively influence the validity of the results. Furthermore, now that VR is on the verge of becoming a technology for mass entertainment and that major international companies are investing billions of dollars in the consumer branch of VR, the effect of ethanol on a VR experience becomes relevant[33–35]. It is therefore important to gain an understanding of how ethanol intake affects presence to define key variables for VR industries and consumers alike. This question can be further abstracted as to what influence drugs have on presence in general and especially in medical VR applications. Such applications could use VR for surgical training as well as phobia or PTSD treatment, especially as alcohol dependent patients often suffer from a comorbid phobic disorder[36–38]. These VR scenarios might involve some level of drug influence, either on the patient using VR or on the physician, e.g. influenced by narcotic gases or drugs evaporating from the patient.

An exploratory research into the effects of ethanol on presence does consequently have high relevance, as it is widely consumed, accepted in most societies and easy to access[35]. Therefore, it is a potential confounder for presence and user experience in most VR applications. To date, to the authors' best knowledge, there is no baseline data on how ethanol could influence presence and user experience, and how it may influence their association in VR. This given exploratory study aims at contributing towards a basic understanding of this complex topic. Using a similar study setting as in our previous study, researching presence and its connection to user experience[15], this study addresses the following hypotheses:

- H1: Ethanol consumption will affect presence and user experience in VR, due to altered perception, cognition and emotion.
- H2: Ethanol consumption will influence the association between presence and user experience in VR due to altered perception, cognition and emotion.
- H3: The kinetics of ethanol breakdown influences presence and user experience in VR, with different effects on presence and user experience in those metabolizing ethanol quicker than the median in a representative cohort.

Methods

Study Setup. The given hypotheses were tested in a prospective exploratory study design with a retrospective control group. Ethanol consumption was defined as an independent variable and 11 dependent variables for presence, usability and user experience for the participants of the exploratory arm. Institutional approval was obtained from the Institute for Machine Tools and Production Processes of the Chemnitz University of Technology, and ethical approval was obtained from the University of Leipzig (number: 251/17-ek). All participants provided written and informed consent. The experiments were conducted according to the principles of the Declaration of Helsinki.

For the non-ethanol condition, data from a previously published study, investigating the effects of presence on usability and user experience in virtual and real environments, was used[15]. This study used a combined virtual scenario and a real geocaching experiment to navigate in the city center of Chemnitz, Germany. The control group was representative of an average sample of the general population. To ensure comparability between the control group and the ethanol group, the study protocol from the previously published study[15] was adapted to include ethanol consumption and breath ethanol measurements. The protocol consisted of three parts: (1) pre-assessment, (2) main study and (3) post-assessment (see Fig. 1). All demographic variables (age, gender and education) were obtained, as well as a self-assessment on the participants' abilities to navigate with digital and paper-based maps, and their familiarity with geocaching and previous VR experience. The adaptation in the study protocol only concerned the pre- and the post-assessment; the main part of the study was conducted in exactly the same way. The pre-assessment was altered from the previous protocol in a way that the participants performed an initial ethanol measurement, followed by the intake of a small meal (half a bread roll with cheese) and the ethanol mixed with orange lemonade, and a waiting time of 30 minutes followed by a second ethanol measurement. The post-assessment was only adapted to include an ethanol measurement right after the participants finished the main study and before they filled out the questionnaires. To ensure comparability between the study and the control group, the demographics questionnaire was extended by two items; surveying the frequency and the amount of alcohol intake by the participants. Baseline data from the previously published study[15] was conducted three months prior to the acquisition of the data in this present study.

In the main study the participants performed a geocaching game with a smartphone application in the virtual city center of Chemnitz, Germany. The Actionbound application from Simon Zwick and Jonathan Rauprich GbR[39] was used for the geocaching game, consisting of a tour of seven locations with a total length of 1.7 km. The participants used a digital map displaying the city center, their present position, and the location of the next point, to help them find the sought-out location. Every participant was asked to solve the same tasks in the same sequence. The experiment took place in a five-sided CAVE (Cave automatic Virtual Environment) at the Virtual Reality Centre Production Engineering, located at the Chemnitz University of Technology, Germany (Fig. 2). The employed CAVE is built on the principles of Cruz-Neira *et al.*[40,41] with an edge length of three meters. A cluster of 11 computers equipped with NVidia Quadro 6000 graphic cards and 20 full HD projectors handled the rear-projection of the images on the sides of the cube. To achieve stereoscopic vision, passive circular polarization was used. An optical infrared tracking system by ART GmbH (Weilheim i. OB., Germany) with six cameras was used to track the orientations and position of the participants' heads to calculate the respective point of view in the virtual world. The tracking of the smartphone in the virtual city center was simulated with an artificial GPS signal. For locomotion in the virtual environment we used a gesture based navigation system developed by Lorenz *et al.*[42] that uses a Microsoft Kinect body tracking system. It recognizes the participants' skeletons filmed from behind. The usage of this locomotion method in previous studies showed, that for some people the tracking was

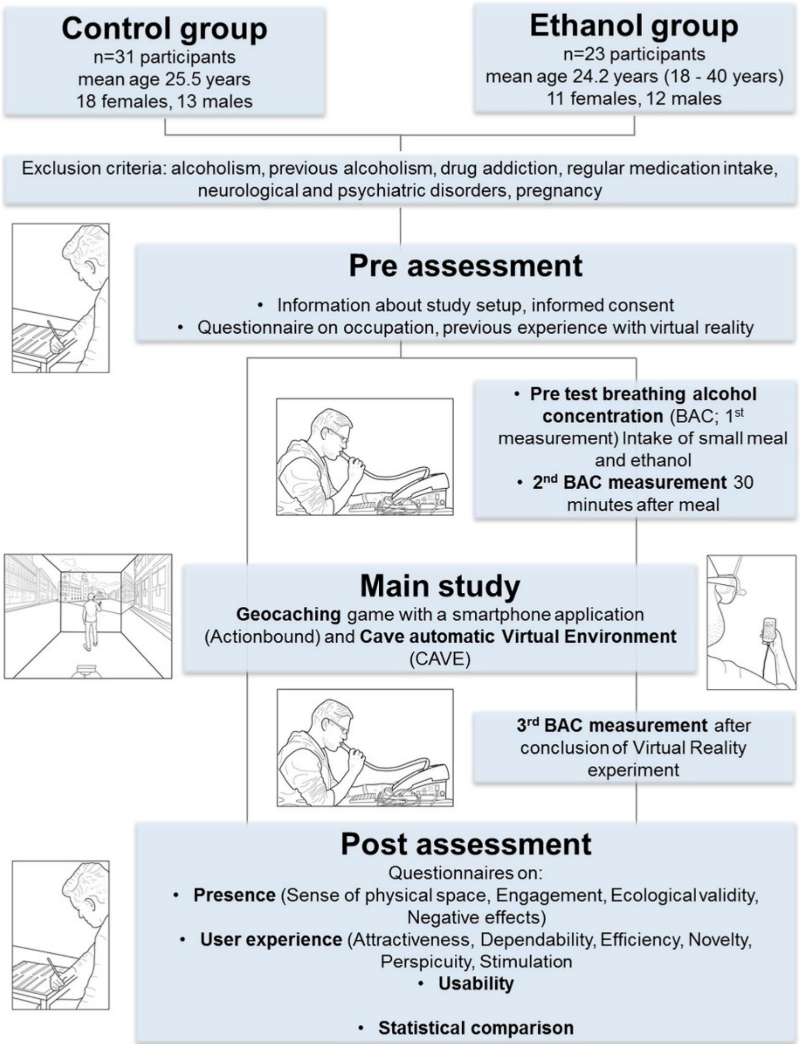

Figure 1. Graphical representation of the study procedure (Drawings by Robbie McPhee).

less stable and that some had more difficulty controlling their movements in the VR scenario than others. But the vast majority considered it a good method for locomotion[42,43]. Following the main part, the dependent variables were obtained in the post-assessment with post-test questionnaires.

Recruitment. The participants for the ethanol group were recruited using social media. Inclusion criteria was the occasional to regular consumption of ethanol in social contexts, excluding alcoholics, sober alcoholics, people with psychiatric or neurological disorders, people who regularly medicated or had any health grounds dissuading them from the consumption of ethanol, and were not suspected to be pregnant. The demographic variables such as age, sex and educational background were matched to the control group. The participants of the non-ethanol group were recruited using social media and the mailing lists of the faculties of the Chemnitz University of Technology. Inclusion criteria was age between 18 and 40. The principal investigators asked the

Figure 2. The virtual environment (CAVE) showing the city center of Chemnitz, Germany.

	Control Group	Ethanol Group
Gender	Female: 18 (58%)	Female: 11 (48%)
	Male: 13 (42%)	Male: 12 (52%)
Professional occupation	Students: 24 (77%)	Students: 10 (44%)
	Other: 7 (23%)	Other: 13 (56%)

Table 1. Distribution of participant gender and professional occupation for the control and ethanol groups.

participants prior to the study about their last ethanol consumption and paid attention to them displaying no sign of ethanol or any other drug intoxication.

Participant sample. Twenty-three participants took part in the experiment for the ethanol group. The sample size of the control group was 31. Table 1 gives an overview of the participants' distribution, their gender and professional occupation. Table 2 shows the distribution of the age of the participants, the results of their self-assessment in the ability to read a map, and the distribution of their previous contact with virtual reality systems and geocaching, for both the control and ethanol groups. The *P*-values of a Mann-Whitney-U-test are also presented, showing that there were no differences between the groups.

Independent Variable: Ethanol Consumption. Following initial information about the nature of the research the participants completed the pre-assessment, including the first measurement of the ethanol level. This measurement was taken to ensure that the participants were sober prior to the experiment. The measurement was carried out with the Dräger Alcotest 9510 (Fig. 3), the only device that is presently admissible as evidence in legal proceedings. The Alcotest 9510 has a measuring range of 0–3 mg/l and a standard deviation of < 0.006 mg/l, thereby providing sufficient accuracy. Every measurement took five minutes and consisted of two measuring processes from which the values were averaged. The time and values of the measurements were recorded in the study protocol. Following this the participant ate a small meal – half a bread roll with cheese, followed by the ethanol mixed with orange lemonade. As we did not want to exceed a blood alcohol concentration (BAC) of 0.4‰, we calculated the quantity of ethanol based on height, weight, age and gender of the participant. For this purpose the Widmark formula, with Watson's extension[44], was used. Two further measurements were taken, one 30 minutes after the drink and the last one after finishing the CAVE experiment, approximately 20 minutes later. Lastly, the participants filled out the post-assessment questionnaires.

Group	P-value	Control Group	Ethanol Group
Age (mean)	0.79	25.5	24.2
		(SD = 7.2)	(SD = 3.9)
Ability to read a map (paper)	0.73	excellent = 12 (39%)	excellent = 7 (30%)
		good = 15 (49%)	good = 10 (45%)
Ability to read a map (mobile)	0.60	excellent = 9 (29%)	excellent = 5 (22%)
		good = 18 (58%)	good = 13 (57%)
Previous contact with VR-systems (yes)	0.73	8 (26%)	5 (22%)
Previous contact with geocaching (yes)	0.07	11 (35%)	3 (13%)

Table 2. Distribution of participant age, results of the self-assessment in ability to read a map and distribution of previous contact with virtual reality systems (CAVE) and geocaching, for the control and ethanol groups including *P*-values (Mann-Whitney-U) testing for differences between the groups

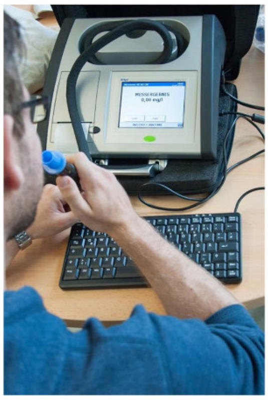

Figure 3. Measurement of the ethanol level with the Alcotest 9510 (Dräger, Lübeck, Germany).

Measure: presence. The International Test Commission – Sense of Presence Inventory (ITC-SOPI) by Lessiter *et al.*[23] was used for evaluating presence. The ITC-SOPI rating scale is made up of 44 items and four factors. The four factors are:

Ecological validity. Describes the users feelings of the believability, realism and naturalness of the displayed environment ("The content seemed believable to me")[23].

Engagement. Describes the interest and the involvement of the users in the displayed environment, their interest in the content and their general joy of the VR experience ("I felt myself being drawn in")[23].

Negative effects. Describes all negative effects in occurrence with the VR experience, e.g. nausea, mild dizziness or kinetosis ("I felt disorientated")[23].

Sense of physical space. Describes the users feelings of physically being within the displayed environment and the feeling to interact and control objects ("I felt as though I was participating in the environment")[23].

A short version of the ITC-SOPI with only the three top loading items per scale had been used as shown previously[15] for the control group. The rating of each statement was made on a five-point Likert scale.

Measure: user experience. User experience[45] is defined as to how users subjectively assess a product, combining usability factors such as efficiency, dependability, fault tolerance, learnability and effectiveness with aesthetics, joy-of-use and attractiveness[46]. For measuring user experience the validated user experience questionnaire (UEQ) by Laugwitz *et al.*[47] was used. The questionnaire included 26 bipolar items divided into 6 scales:

Attractiveness. Describes the users general impression of the product[46].

	Frequency of ethanol consumption
2–4 times a month	13 (57%)
2–3 times a week	6 (26%)
4 or more a week	4 (17%)

Table 3. Distribution of participant frequency of ethanol consumption within the ethanol group.

Dependability. Describes the users feeling if the interaction with the product was easy and predictable and the feeling of having control over the interaction[46].

Efficiency. Describes how quickly and efficiently the user could operate the product[46].

Perspicuity. Describes how easily the user could understand the product[46].

Novelty. Describes whether the design of the product was perceived innovative, creative and aroused the attention of the users[46].

Stimulation. Describes the users interest and excitement of the product and their interest to continuously use the product[46].

The scales efficiency, dependability and perspicuity describe the pragmatic quality of the product, whereas the scales novelty and stimulation relate to its hedonic qualities. The scale attractiveness represents a positive or negative attitude to the product. Participants were asked to rate the items using a seven-point semantic differential. UEQ results had been utilized from previous data as the measure of the user experience for the control group[15].

Measure: usability. How the user assesses the fitness of use of a product is described by the term 'usability', which also represents the pragmatic aspect of user experience. To measure usability, the systems usability scale (SUS) by Brook[48] was used, in accordance with the control group[15]. The SUS consisted of ten items that were rated on a Likert scale ranging from zero to four.

Statistical Methods. To compare the results between the conditions, a Mann-Whitney-U or Student's t-test was used, depending on whether the samples showed a normal distribution, as indicated by the Kolmogorov-Smirnov-test. The effect sizes for the differences of means were calculated using the Z-scores of the Mann-Whitney-U-test as described by Fritz *et al.*[49]. The two-tailed Spearman test was used to compute correlations of factors in both the ethanol and control groups. The average ethanol breakdown per hour of each participant was calculated from their second and third ethanol measurements and the time between both measures. The median was used to subdivide the sample into fast and slow ethanol metabolizer groups. Those participants who had a breakdown rate above the median were considered fast metabolizers, and those participants who had an equal or below the median, slow metabolizers.

Data availability. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Results

Ethanol consumption characteristics. Table 3 summarizes the distribution for participant frequency of ethanol consumption. The assessment of drinking behavior showed that 10 (44%) of the participants did not consume ethanol without a social occasion. Whereas within a social occasion, 14 (62%) of the participants consumed up to four glasses of ethanol-based drinks (Table 4). One glass of ethanol equals 0.33 l beer, 0.25 l wine/sparkling wine or 0.02 l spirits. None of the participants identified themselves as addicted to ethanol, nor was there evidence from the psychological assessment regarding alcoholism in either of the groups. Consequently, statistical comparison yielded no significant differences between the groups ($P = 1.00$).

Prior to the experiment all of the participants' breath ethanol concentration measurements showed 0.00‰. Further to this no other signs of drug influence were identified. Thirty minutes after the ethanol intake the participants reached an average of 0.11 mg/l (SD = 0.03), with a 95% confidence interval of 0.09 to 0.13, corresponding to a BAC of 0.23‰ (conversion factor 2.1)[50]. An ethanol intake-related increase in the ethanol measures was observed in all participants. In the third measurement, after completing the experiment, the mean breath alcohol level was 0.06 mg/l (SD = 0.03) equating to a BAC of 0.13‰. The ethanol intake related BAC did in not exceed 0.4‰ in any of the participants during the experiments.

Psychometric properties of the scales. The Cronbachs' alpha values for the scales of the ITC-SOPI, SUS and UEQ reached values of 0.50 or more with the only exception being the efficiency factor from the UEQ. The efficiency factor from the UEQ was therefore excluded from further analyses, but will be listed for the sake of completeness. All Cronbach's alpha values can be found in the supplement files.

H1: Influence of ethanol intake on presence, usability and user experience. Table 5 shows the mean values, standard deviations and medians of all factors for presence and user experience along with the associated P-values and η^2-values for the effect size. They showed no significant differences between the ethanol and

Glasses	Ethanol consumption with social occasion
1–2	4 (17%)
3–4	10 (45%)
5–6	4 (17%)
7–8	4 (17%)
9 or more	1 (4%)

Table 4. Distribution of participant quantity of ethanol consumption within a social occasion (indication in glasses) within the ethanol group.

the control groups for any factor. Also the effect sizes showed no or only a small effect[51]. Figure 4 shows boxplots for the presence factors of the ethanol and control groups, Fig. 5 for usability and Fig. 6 for the user experience factors.

H2: Influence of ethanol consumption on the connection between presence, usability and user experience. Tables 6 and 7 show the correlations of the presence factors with the user experience factors for the ethanol and the control groups. In the control group 18 of 28 correlations were found to be at a significant level, whilst in the ethanol group only seven correlations were observed. The calculation of partial correlations did not give adequate results, as a graphical analysis showed that the correlations were strongly nonlinear.

H3: Influence of ethanol metabolism on presence, usability and user experience. The median for the ethanol breakdown of the participants was 0.11 mg/l (0.23‰.) with 11 participants in the fast metabolizers group and 12 participants in the slow metabolizers group. The median, as a statistical criterion, was chosen for two reasons. First, a formal average ethanol breakdown rate does not exist. As a rule of thumb 0.16‰ is often used as the average ethanol breakdown rate. However, even within an individual the average breakdown rate can change depending on various factors[50]. Moreover, as Jones[50] showed there is a corridor ranging from 0.1‰ to 0.25‰, with either one of these values used in legal-forensic questions, e.g. to determine if a suspect following a crime could have been drunk and incapacitated, or vice versa if a suspect claiming to have consumed a minute quantity of ethanol following a conviction comes up with a reasonable explanation[52]. Second, by splitting the ethanol group using the median results into two groups containing 12 and 11 samples respectively. These group sizes justified the use of a test for significant differences. By using the rule of thumb ethanol break down rate of 0.16‰ group sizes of N = 15 for the fast metabolizers and N = 8 slow metabolizers would result, therefore not justifying a significant test.

Table 8 shows the mean values, standard deviations and median of the fast and slow metabolizers. Significant differences could be found between the fast and slow metabolizers in the presence factor (negative effects) and in the user experience factor (perspicuity), both showing large effects.

Summary of the results. The given results of this study have shown that no significant difference between the ethanol and control group could be detected for any of the factors of the ITC-SOPI, SUS and UEQ questionnaire (Table 5). It was further found that seven of the 28 factors correlated significantly in the ethanol group, in contrast to 18/28 factors in the control group (Tables 6 and 7). These differences in the number of significant correlations between both groups were particularly strong for the presence factors 'Sense of physical space (2 vs. 5)', 'Engagement (1 vs. 5)' and 'Ecological validity (2 vs. 5)'. For the 'Negative effects' there was only a difference of 2 vs. 3 (Tables 6 and 7). The results for the comparison of fast vs. slow ethanol metabolizers revealed significant differences for the factors 'Perspicuity' and 'Negative effects' (Table 8).

Discussion

This VR-based study determined, for the first time, the influence of low-level ethanol consumption on presence and user experience.

Being present in a virtual environment can have a number of interesting physiological and psychological effects, as the phenomenon of simulator sickness impressively shows[6,53]. The same is also said for the use of VR to treat phobias and cerebral stroke[3–5]. The phenomenon of body ownership in a virtual avatar[54,55] or even an induced higher dissociation[56] are fascinating examples that prove the strong physical and psychological effects VR can have on a person. Though the deeper perceptive and cognitive processes explaining the aforementioned examples and underlying phenomena, are still subject of ongoing research.

One approach which may potentially contribute to identify underlying neural mechanisms in the formation of presence are the acute and long-term effects of ethanol on the physiological and neural pathways of the brain[28–32]. A number of studies have investigated the alterations in functional connectivity[57–59], with effects on perception, motor control, memory and cognitive performance. Anatomical regions related to the changes in these areas are the thalamus[58], the superior frontal gyrus, cerebellum, hippocampal gyrus, basal ganglia, right internal capsule[59], the posterior cingulate cortex and the precentral gyrus with the sensorimotor network[57]. Kleinloog *et al.* have shown that the posterior cingulate cortex plays a vital role in visuospatial evaluation, and its function is altered as a consequence of ethanol intake. Luchtmann and co-workers analyzed ethanol-induced effects on the visuomotor system in 3 T magnetic resonance imaging at a BAC of 1.0‰[60], demonstrating that this BAC appears to selectively disturb the connectivity between different brain areas such as the primary visual cortex, the supplementary motor area, and the left and right primary motor cortex[60]. Furthermore, they concluded that complex tasks requiring

	P-value	η^2-value	Control Group	Ethanol Group
Ecological validity	0.39	0.014	3.35 (SD = 0.69)	3.48 (SD = 0.60)
			3.33	3.33
Engagement	0.56	0.006	4.15 (SD = 0.73)	4.11 (SD = 0.57)
			4.33	4.33
Negative effects	0.27	0.023	2.09 (SD = 0.86)	1.83 (SD = 0.80)
			1.67	1.67
Sense of physical space	0.57	0.006	3.34 (SD = 0.89)	3.51 (SD = 0.80)
			3.67	3.67
Usability	0.60	0.005	82.98 (SD = 9.23)	84.23 (SD = 8.71)
			85.00	87.50
Attractiveness	0.41	0.013	1.73 (SD = 0.75)	1.54 (SD = 0.74)
			1.67	1.67
Dependability	0.13	0.042	1.05 (SD = 0.76)	1.35 (SD = 0.80)
			1.00	1.25
Efficiency	0.24	0.026	1.28 (SD = 0.61)	1.40 (SD = 0.62)
			1.25	1.25
Perspicuity	0.92	<0.001	2.01 (SD = 0.66)	1.93 (SD = 0.91)
			2.00	2.25
Novelty	0.76	0.002	1.62 (SD = 0.86)	1.62 (SD = 0.84)
			1.50	1.75
Stimulation	0.24	0.026	1.82 (SD = 0.91)	1.60 (SD = 0.73)
			2.00	1.50

Table 5. Means, standard deviations (first row) and medians (second row) of the presence, usability and user experience factors for the control and ethanol groups with their *P*-values (Mann-Whitney-U) for significance testing and η^2-values for effect sizes.

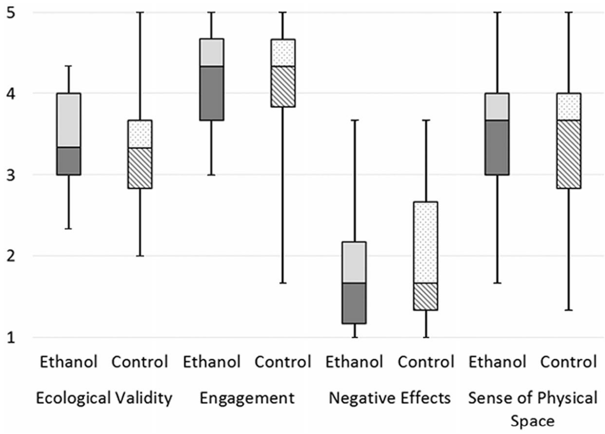

Figure 4. Boxplot of the presence factors for the ethanol group and for the control group. Whiskers indicate the 25^{th} and 75^{th} percentiles.

interaction or synchronization become affected even at moderate levels of alcohol. Though our given VR study has assessed much lower BAC levels, we may hypothesize that changes to brain connectivity may be similar but less pronounced in a dose-dependent manner. The study of Zheng *et al.* using functional magnetic resonance imaging could show consistent change in the functional activation and connectivity and of the superior frontal gyrus, cerebellum, hippocampal gyrus, left basal ganglia, and right internal capsule by ethanol[59]. This group concluded that the change in activity and connection may contribute to altered cognitive abilities and behavioral performance, underlining the findings from our study. Equally, alcohol-induced effects on the resting-state functional connectivity of the visual network appear to be selectively altered by acute alcohol consumption[61]. Though this effect may be less pronounced in low BAC levels, it may have implications for presence and user

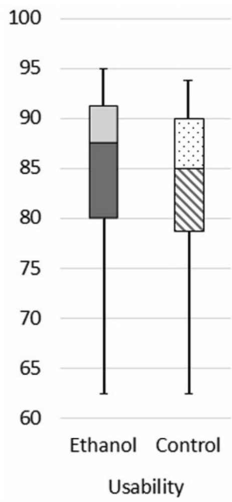

Figure 5. Boxplot of the usability for the ethanol group and for the control group. Whiskers indicate the 25th and 75th percentiles.

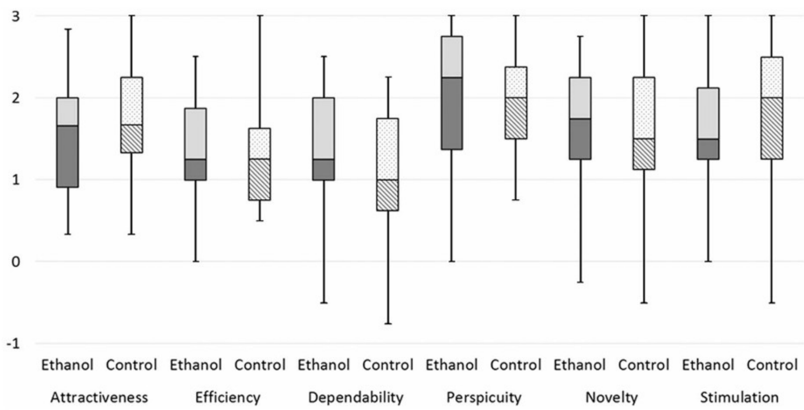

Figure 6. Boxplot showing user experience factors for the ethanol group and for the control group. Whiskers indicate the 25th and 75th percentiles.

experience, as our data have shown. Future studies may show correlations between ethanol-induced impairments and changes in presence. Such observations could then reveal a part of physiological and neural pathways involved in the formation of presence.

It is important to understand the influence of drugs including ethanol on presence in VR, in light of the aforementioned effects. VR is no longer solely used for scientific purposes but has become a broadly available tool for entertainment and professional applications. To address the effects of ethanol a five-sided CAVE was used in which the participants took part in a geocaching tour whilst being influenced by ethanol with blood alcohol concentrations lower than 0.4‰. Surprisingly, the comparison of the ethanol group to the control group revealed that hardly any differences existed regarding the factors of the ITC-SOPI, SUS and the UEQ questionnaires, shown by the respective mean (median) scores and a comparably small standard deviation for all factors, indicating similarity. The high *P*-values for almost all factors and the η^2 showing no or only minute effects, emphasize our statement, despite the limitations of our study. Our hypothesis 1 claiming that ethanol consumption will affect presence and user experience therefore has to be rejected for the low-dose ethanol intake scenario investigated here. It can be concluded for

	Ecological validity		Engagement	
	Control Group	Ethanol Group	Control Group	Ethanol Group
Attractiveness	**0.61 ($P < 0.001$)**	**0.53 ($P = 0.009$)**	**0.84 ($P < 0.001$)**	0.37 ($P = 0.08$)
Dependability	**0.66 ($P < 0.001$)**	0.36 ($P = 0.09$)	0.28 ($P = 0.13$)	0.04 ($P = 0.87$)
Efficiency	0.32 ($P = 0.08$)	0.32 ($P = 0.14$)	**0.46 ($P = 0.009$)**	0.001 ($P = 1.00$)
Perspicuity	**0.49 ($P = 0.005$)**	0.27 ($P = 0.22$)	**0.42 ($P = 0.02$)**	0.34 ($P = 0.12$)
Novelty	0.28 ($P = 0.12$)	**0.41 ($P = 0.05$)**	0.31 ($P = 0.09$)	0.28 ($P = 0.20$)
Stimulation	**0.45 ($P = 0.01$)**	−0.03 ($P = 0.88$)	**0.46 ($P = 0.009$)**	0.06 ($P = 0.80$)
Usability	**0.42 ($P = 0.02$)**	0.19 ($P = 0.38$)	**0.57 ($P = 0.002$)**	**0.42 ($P = 0.04$)**

Table 6. User experience factors and usability correlated (Spearman, two-tailed) with presence factors ("Ecological validity" and "Engagement") for the ethanol and control groups. With *P*-values (bold fields are significant).

	Negative effects		Sense of physical space	
	Control Group	Ethanol Group	Control Group	Ethanol Group
Attractiveness	−0.14 ($P = 0.47$)	−0.13 ($P = 0.54$)	**0.65 ($P < 0.001$)**	**0.52 ($P = 0.01$)**
Dependability	**−0.49 ($P = 0.005$)**	−0.32 ($P = 0.13$)	0.32 ($P = 0.08$)	0.31 ($P = 0.16$)
Efficiency	−0.11 ($P = 0.57$)	−0.27 ($P = 0.22$)	**0.44 ($P = 0.01$)**	0.25 ($P = 0.25$)
Perspicuity	**−0.36 ($P = 0.048$)**	**−0.68 ($P < 0.001$)**	0.32 ($P = 0.08$)	0.18 ($P = 0.41$)
Novelty	0.20 ($P = 0.28$)	−0.20 ($P = 0.37$)	**0.42 ($P = 0.02$)**	**0.58 ($P = 0.004$)**
Stimulation	−0.09 ($P = 0.65$)	−0.38 ($P = 0.07$)	**0.49 ($P = 0.005$)**	0.21 ($P = 0.33$)
Usability	**−0.50 ($P = 0.004$)**	**−0.72 ($P < 0.001$)**	**0.36 ($P = 0.045$)**	0.27 ($P = 0.21$)

Table 7. User experience factors and usability correlated (Spearman, two-tailed) with presence factors "Negative effects" and "Sense of physical space") for the ethanol and control groups. With *P*-values (bold fields are significant).

	P-value	η^2-value	Slow metabolizers	Fast metabolizers
Ecological validity	1.00	<0.001	3.47 (SD = 0.63)	3.48 (SD = 0.60)
			3.50	3.33
Engagement	0.52	0.019	4.03 (SD = 0.64)	4.21 (SD = 0.50)
			4.00	4.33
Negative effects	**0.049**	**0.170**	**2.19 (SD = 0.93)**	**1.42 (SD = 0.40)**
			2.00	**1.33**
Sense of physical space	0.77	0.004	3.39 (SD = 0.99)	3.64 (SD = 0.55)
			3.67	3.67
Usability	0.57	0.015	82.71 (SD = 9.97)	85.91 (SD = 7.18)
			83.75	87.50
Attractiveness	0.87	0.001	1.50 (SD = 0.70)	1.58 (SD = 0.82)
			1.58	1.67
Dependability	0.25	0.060	1.15 (SD = 0.81)	1.57 (SD = 0.78)
			1.25	1.75
Efficiency	0.29	0.052	1.23 (SD = 0.69)	1.57 (SD = 0.50)
			1.25	1.50
Perspicuity	**0.009**	**0.284**	**1.48 (SD = 0.95)**	**2.43 (SD = 0.57)**
			1.50	**2.25**
Novelty	1.00	<0.001	1.63 (SD = 0.86)	1.61 (SD = 0.87)
			1.75	1.75
Stimulation	0.46	0.026	1.44 (SD = 0.81)	1.77 (SD = 0.62)
			1.50	1.75

Table 8. Means, standard deviations (first row) and medians (second row) of the presence, usability and user experience factors for the fast and slow metabolizers and their *P*-values (Mann-Whitney-U) for significance testing (bold fields are significant) and η^2-values for effect size.

the given sample and VR scenario that perceptive, cognitive and emotional aspects are similar and non-different between user experience and presence in the geocaching task between the control and ethanol groups.

In our previous published study[15] using the same virtual scenario we could show that all presence factors correlated significantly with usability, and that most of them correlated with the user experience factors. Furthermore, we could show that presence and user experience factors are key indicators of validity when evaluating a product or system consisting of hard- and/or software in VR. Under the influence of ethanol, the participants were less influenced by presence in the assessment of usability and user experience. However, this correlation does not indicate a causal relationship between presence and user experience. Of the 28 possible correlations, only seven were found to be statistically significant. All of these seven correlations were moderate to high for the ethanol group (correlation coefficients larger than 0.3 and 0.5, respectively). In contrast, moderate or strong correlations were found for the control group with 18 of 28 possible correlations. The differing number of samples within each group is unlikely to explain this difference in correlations between user experience and presence. A close analysis of the *P*-values and correlation coefficients supports this statement. For those significant correlations, almost all *P*-values were very low and far from being borderline. Additionally, the differences in the correlation coefficients for significant correlations between the ethanol and control groups can be considered strong, e.g. for the correlation of ecological validity with stimulation the correlation coefficient is −0.03 in the ethanol group vs. 0.66 in the control group. These unexpected results indicate that a low dosage of ethanol might contribute to a disconnection between presence and user experience. These findings help to gain an important insight into subconscious and externally non-perceivable effects of ethanol consumption, whilst having a VR experience. The underlying central nervous system mechanisms causing this effect in VR are to date not completely known, and conclusions driven at this stage might be largely speculative. However, extensive research on ethanol as a pharmacological agent and psychoactive substance has been performed. It has been shown that ethanol does have manifold effects on the cortical regulation system[62,63]. Follow-up studies will need to clarify which of these effects, or which effect combination, may cause the disconnection between presence and user experience. Work that may give direction in this regard is that of Semmens-Wheeler *et al.*[64], who found out that frontal lobe activity plays a critical role in responsiveness to hypnosis. One may hypothesize that a hypnotic experience can in some ways be seen as loosely related to a VR experience, as the participants' perception system is targeted to induce a simulated experience to be perceived as real. Creating such a disconnection of presence and user experience may therefore be desirable to outbalance the existing shortcomings of VR systems in the application development for entertainment and professional scenarios. Vice versa, in games in a VR environment such disconnection might lead to a less enjoyable experience under the influence of low dose ethanol compared to the sober state. In professional applications, the supporting effect of presence on learnability may be removed when under the influence of confounders, leading to an inferior learning effect. Our hypothesis 2, stating that the consumption of ethanol has an influence on the correlations between presence and user experience, can therefore be accepted.

Comparison of the mean values between subjects from the fast and slow metabolizer groups revealed similar mean values and standard deviations for all presence and user experience factors with the only exceptions of negative effects and perspicuity. However, the effect size of the differences for negative effects and perspicuity were large[51]. As perspicuity describes how easy it is to understand, learn and use a product, one can conclude that the high metabolizers in our study understood the usage of the product more easily. The high metabolizers also suffered far less from negative effects of the VR experience. The effect sizes for the other three presence values showed no, or only a small effect, and also the *P*-values revealed no significant differences. This indicated that there is likely no difference between the fast and the slow metabolizers. Despite a clear difference for perspicuity, three other user experience factors and usability showed ambiguous results. Whilst the *P*-values for efficiency, dependability, stimulation and usability showed no significant differences, the η^2-values demonstrated small or medium effect sizes. If these factors are influenced by ethanol breakdown kinetics remains unclear. Future research should concentrate on these factors. The remaining user experience factors, attractiveness and novelty, show no significant differences and no effect indicating that they are unaffected by ethanol breakdown kinetics. Further, there were no correlations between ethanol breakdown kinetics and presence or user experience. Our hypothesis 3 claiming that ethanol breakdown kinetics do influence presence and user experience and usability consequently can neither be rejected nor accepted on the basis of our data. Moreover, our data calls for more in-depth research on this topic.

Our study yielded a number of results with impact on VR in a psychological-medical-social context. Although a low dosage of ethanol barely caused differences in means, standard deviations and medians, there was a notable difference in the number of significant correlations (7 vs. 18). More specifically, this has implications regarding existing studies on the conceptual context of presence. One may speculate that under the influence of low dosages of ethanol the mode of decision-making is altered, or the way in which people report their experience in VR. Although this alteration does not necessarily change a decision or a rating itself, as the results for the user experience showed, it might have changed the rationale behind these decisions. This hypothesis could also initiate further investigation on how low dosage ethanol exposure is biasing the treatment results of classic VR involving therapies for phobias, stroke rehabilitation and PTSD. These methods should research if low dosage ethanol consumption has a strengthening, weakening or no influence on the therapy. The results of these studies should be considered when applying VR involving therapies. To emphasize this research and how ethanol may influence VR involving phobia treatments is especially relevant as alcohol-dependent patients often suffer from comorbid phobic disorders[36–38]. Therefore, it seems likely that some patients receiving phobia treatment, using VR technology, may be under the influence of ethanol. In light of our results future research should, in our opinion, concentrate on the effects different ethanol dosages and ethanol breakdown kinetics in alcohol-dependent patients have on presence and how it possibly affects phobia treatment results. In the context of VR drunk driving studies, our results indicate that low dose ethanol consumption does not necessarily change the perceived presence and user experience in a general group. This supports the credibility of the conducted research in the area of drunk driving studies using VR as an experimental environment. However, this applies only for low dosage ethanol consumption (<0.4‰). As far as higher ethanol dosages are concerned, commonly used in drunk driving studies, it remains unclear how presence and its connection to the typical measures used in this area are affected. Further research into the influence of different ethanol dosages on presence and its connection to the typical measures used in VR drunk driving studies, are recommended. Not only could such research improve future advancements in the aforementioned area, but it could also lead to a change in the interpretation of the existing results of conducted VR drunk driving studies. A further application area where the measured effects of our study could be relevant in future are VR-induced mental disorders, like PTSD, by playing VR video games. Currently the occurrence of such mental disorders is highly speculative and in fact no such cases have yet been reported. However, this might be reasoned by the unavailability of highly immersive VR battle games and that VR systems among consumers are still not widespread. However, such VR battle games and the required VR systems will very likely be available and widespread in the next years. Given it is most likely that the processes responsible for forming presence in the real world and VR are the same[18,19], this may have strong implications for the onset of PTSD. For the authors it seems therefore highly likely that such disorders can also be induced through VR. If the consumers of VR battle games are feeling very present on the virtual battleground than why should they not be under the risk of suffering from PTSD especially when playing for hours? If this speculation turns out to be true, then also perception and cognition altering drugs like ethanol might play a role here, as they are an integral part of human culture[35]. Also, the successful treatment of PTSD patients with VR exposure therapy[1] underline the psychological impact VR can have.

This given study presents a study protocol for researching the effects of ethanol in a VR environment, which could potentially serve as a starting point to further elucidate the effects of other substances on perception in a VR entertainment. However, to understand the effects of other substances on perception, a more elaborate study protocol is needed. It would require tasks that investigate more than spatial localization and somatosensory perception of goal-directed actions, such as a geocaching task. These tasks should include decision-making, risk-taking, craving assessment and the effect of drug-related cues which can be adapted from other studies in these fields[65–67]. This might especially be relevant for psychoactive or psychotropic drugs, sedatives, narcotics and gas anesthetics used in a hospital environment. In hospitals, today, patients with burn injuries or psychiatric disorders are already candidates to receive VR as a complementary treatment option. In a recent review on VR in mental health disorders, Freeman *et al.*[1] also list VR treatment applications for psychosis like schizophrenia and substance disorders. Additionally, Dascal *et al.*[68] and Hoffmann *et al.*[69,70] demonstrate how pain ratings in burn-injury patients could be reduced effectively, distracting them using VR. However, it needs to be pointed out that drugs have differing effects on the central nervous system, which may also alter the decision-making process. Our study points out that there is a lack of questionnaires available to measure presence under the influence of ethanol. Therefore, the existing presence questionnaires should be improved in this direction or new ones developed.

A number of limitations need to be addressed for this study. First, only a limited number of participants were available due to the timeframe and the elaborate technical setup. Second, the VR scenario for geocaching has limitations regarding the mode of locomotion. Participants handled the locomotion with the Microsoft Kinect body tracking system differently, meaning that a few participants struggled more with controlling their movements inside the VR scenario, whilst the majority had no problems. This concerned four participants in the control group and one participant in the ethanol group who had issues controlling their movements, despite the tracking system working well. Second, the body tracking system worked differently between the participants, which is a known technical issue of the Microsoft Kinect sensor and its detection algorithms. One participant in each group suffered from bad body tracking. Using a more stable tracking sensor in future would probably resolve this issue. A qualitative analysis of the seven participants experiencing problems with the navigation gave no justification for an exclusion of their data sets. For each of the seven data sets it was evaluated if they solely caused the minimum or maximum values for each of the eleven factors of the dependent variables within their respective group. Only two of the seven data sets caused one minimum or maximum value. One other data set solely caused the minimum value for three of 11 factors. The remaining four data sets did not exclusively cause the minimum or maximum value for any of the 11 factors. We performed an analysis of the data without the seven data sets where navigation issues occurred, and the results were non-different (see supplement). Moreover, the Hawthorne effect might have influenced the outcomes of the study especially in respect to ethanol consumption, and also drug tolerance might be a possible confounder, and clear separation criteria were missing to separate slow from fast ethanol metabolizers. The performance at the task was not considered and the effect ethanol consumption had on it. Further, the timing of the last food intake might have played a role in ethanol absorption and breakdown kinetics, which was not substantiated in our present setting, though we tried to standardize this variable by providing a standard meal to each of the participants prior to the ethanol intake. Lastly, detailed ethanol consumption behavior was not obtained for the control group.

Conclusions

This study researched the influence of low-dosage ethanol on presence and user experience in VR. Although the mean values of presence and user experience were similar in the ethanol and the control group, differences in the number of correlating presence and user experience factors were found. These differences indicated that central nervous system mechanisms supporting connections between presence and user experience might already become impaired at low dosages of ethanol. A comparison of the fast with the slow metabolizers showed ambiguous results. There were hardly any significant differences except for two of the 11 factors: perspicuity and negative effects. Future studies researching the effect of higher dosages of ethanol and of other drugs at differing dosages will therefore be of interest. Furthermore, it will be important to perform studies with different tasks and other virtual environments to see if similar results can be found, e.g. can we expect the same effects if people were playing a VR-game using a head mounted display?

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Author Contributions

M.L. participated in the conception and design of the research question, the design and coordination of the study, the technical implementation, conducting the statistical analysis and interpreting the results. J.B. participated in the design and coordination of the study, the technical implementation, conducting the statistical analysis and interpreting the results. L.D. participated in the conception of the research question and the design of the study. D.S. participated in the conception of the research question and provided critical comments on the manuscript. M.B. participated in the design of the study. M.T. participated in the conception of the research question. P.K. participated in the technical implementation. C.E.H. participated in interpreting the results and provided critical comments on the manuscript. N.H. participated the conception and design of the research question, participated in conducting the statistical analysis, interpreting the results and provided critical comments on the manuscript. All authors were involved in drafting the manuscript. All of them read and approved the final version of the manuscript.

Additional Information

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Competing Interests: The authors declare no competing interests.

2.3 Diskussion

Bezogen auf das **Ziel 1** dieser Arbeit, der Art des Zusammenhangs von Presence mit User Experience und Usability, decken sich die vorliegenden Ergebnisse teilweise mit den wenigen vorhandenen Studien zu diesem Thema (s. Abbildung 12). So wurden ähnliche Presence-Werte wie in einer unserer Vorarbeiten gemessen (Busch et al. [93]), obwohl die Evaluationsszenarien der vorliegenden Arbeit und der Arbeit von Busch et al. [93] unterschiedlich sind. Zum ersten Mal gelang mit dieser Arbeit außerdem der Nachweis eines signifikanten Zusammenhangs zwischen Presence und Usability, der in Busch et al. [93] noch nicht gezeigt werden konnte. Zudem wurde ein Zusammenhang von Presence und User Experience gefunden, welcher in der bestehenden Literatur bis dahin noch nicht untersucht worden war.

Die Ergebnisse zum **Ziel 2** dieser Arbeit, der Bewertung des Unterschieds von Presence, User Experience und Usability im Vergleich von VR zur realen Studienumgebung, können aufgrund der unzureichenden Studienlage allenfalls bedingt mit bestehenden Vorergebnissen verglichen werden. Die durchgeführte Studie betrachtete erstmals die Unterschiede der User Experience- und Usability-Bewertungen im Vergleich von realer zu virtueller Umgebung, sowie den Einfluss von Presence auf diese Verbindung. Es konnte analog zu Patel et al. [94] und Sylaiou et al. [95] eine Verbindung von Presence mit der hedonischen User Experience-Dimension in VR gefunden werden. Im Gegensatz zu unseren Vorbefunden [93] wies diese Studie eine signifikant höhere Usability-Bewertung in der realen Umgebung nach. Zudem konnte die Studie erstmals nachweisen, dass nur in einer virtuellen Umgebung ein Zusammenhang von Presence mit User Experience und Usability besteht, allerdings nicht in einer realen Umgebung (s. Abbildung 12).

Ein Vergleich der Ergebnisse dieser Arbeit mit der bestehenden Literatur zum **Ziel 3**, der Untersuchung des Einflusses von Alltagsfaktoren, wie bspw. Ethanol, auf Presence, User Experience und Usability, ist ebenfalls nicht möglich, da derartige Zusammenhänge hier erstmals gemessen wurden. Die Studie konnte zeigen, dass niedrige Ethanolmengen keinen Einfluss auf die Bewertung von Presence, User Experience und Usability zu haben scheinen (s. Abbildung 12). Allerdings ist die nahezu vollständige Auflösung des Zusammenhangs von Presence mit User Experience und Usability bereits bei niedrigen Ethanolmengen feststellbar.

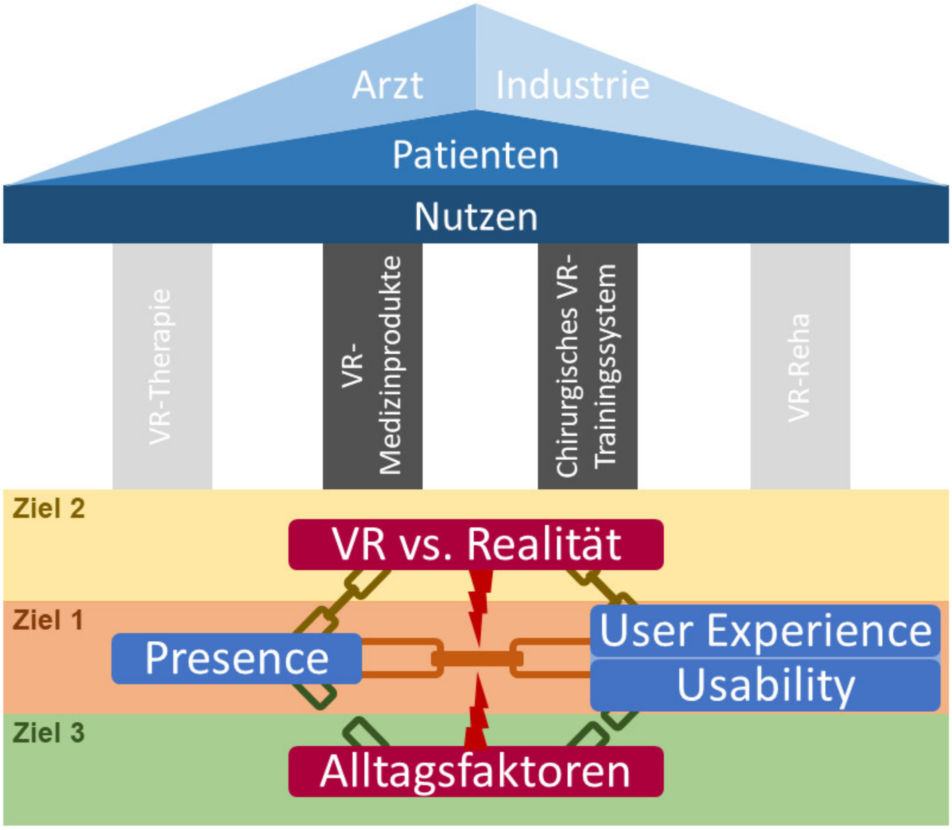

Abbildung 12: Übersicht über die Studienergebnisse bzgl. der drei Ziele dieser Arbeit.

3 Zusammenfassung der Arbeit

Dissertation zur Erlangung des akademischen Grades
Dr. rer. med.

Untersuchung des Zusammenhangs von Presence und User Experience in der Virtuellen Realität als Grundlage für die Entwicklung von Trainingssystemen und Medizinprodukten in der Chirurgie

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3.1 Hintergrund

Virtual-Reality(VR)-Anwendungen sind in der Medizin bereits etabliert und weit verbreitet. Die VR wird zur Aus- und Weiterbildung von Ärzten sowie für die Therapie unterschiedlicher Erkrankungen wie Angststörungen und neurologischen Funktionseinschränkungen eingesetzt. Zudem besitzen VR-Anwendungen das Potential, die Entwicklung von Medizinprodukten zu optimieren. Entscheidend für die Qualität und den Erfolg von medizinischen VR-Anwendungen ist dabei das Verständnis von Presence im Zusammenspiel mit User Experience und Usability unter der Berücksichtigung von Alltagsfaktoren.

3.2 Ziele

Das **erste Ziel** der vorliegenden Arbeit war die Ergründung des Zusammenhangs von Presence mit User Experience und Usability, um Entwicklern von chirurgischen VR-Trainingssystemen einen bestmöglichen Gewinn an Grundlagenwissen und Erfahrung zu ermöglichen.

Das **zweite Ziel** der Arbeit bestand darin, zu quantifizieren, welche Unterschiede bei der Bewertung der User Experience und Usability eines Produktes in VR im Vergleich zur Realität auftreten und welchen Einfluss die Presence darauf hat.

Das **dritte Ziel** der Arbeit war es, einen methodischen Weg für die Evaluation der Wirkung von Alltagsfaktoren auf Presence, User Experience und Usability zu ebnen und anhand einer ersten explorativen Studie für niederdosierte Ethanolmengen zu evaluieren.

3.3 Methoden

Zwei Studien wurden durchgeführt, um Interaktionen zwischen Presence und User Experience bzw. Usability direkt zwischen der realen und der virtuellen Umgebung zu vergleichen, und den Einfluss von Alltagsfaktoren zu evaluieren. Es wurde dieselbe experimentelle Alltagsaufgabe verwendet, um die direkte Vergleichbarkeit der Ergebnisse beider Studien zu gewährleisten und um Baseline-Daten zu erhalten. Beide Studien waren als ‚between-subject'-Design konzipiert und bestanden aus drei Phasen. In Phase 1 wurden demographische Daten erhoben. Für Phase 2, die Durchführung der experimentellen Aufgabe, wurden die Probanden zufällig einer von zwei Gruppen zugeordnet (Gruppe 1 = Kontrollgruppe, Gruppe 2 = Interventionsgruppe). Die experimentelle Aufgabe in der VR wurde in einer 5-Seiten-CAVE (Cave Automated Virtual Environment) durchgeführt. In Phase 3 füllten alle Studienteilnehmer den ITC-SOPI als Presence-Fragebogen, den UEQ als User Experience-Fragebogen und den SUS als Usability-Fragebogen aus.

3.4 Ergebnisse

Die Ergebnisse der Untersuchungen zu **Ziel 1** wiesen nach, dass ein starker Wirkzusammenhang von Presence mit User Experience und Usability existiert. Im Detail zeigte sich, dass alle vier Presence-Faktoren signifikant mit der Usability korrelieren, und 18 von 24 Korrelationen zwischen den vier Presence und den sechs User Experience Faktoren in der VR-Umgebung signifikant waren.

Die Studienergebnisse zu **Ziel 2** zeigten signifikante Unterschiede bei der Bewertung von Presence (3 von 4 Faktoren), User Experience (3 von 6 Faktoren) und Usability zwischen realer und virtueller Evaluationsumgebung. Ebenso bestand ein großer Unterschied bei der Anzahl signifikanter Korrelationen von Presence mit User Experience und Usability im Vergleich der virtuellen zur realen Evaluationsumgebung.

Die Studienergebnisse zu **Ziel 3** zeigten keine Unterschiede von Presence, User Experience und Usability zwischen der Kontrollgruppe und der Gruppe nach Konsumierung niedrigdosierter Ethanolmengen von durchschnittlich 0,23 Promille Allerdings zeigten sich Veränderungen in der Anzahl signifikanter Korrelationen der 4 Presence-Faktoren mit den 6 User Experience-Faktoren der Kontrollgruppe mit 14 von 24 signifikanten Korrelationen und der Ethanolgruppe mit 5 von 24 signifikanten Korrelationen. Auch die Anzahl signifikanter Korrelationen von Presence mit Usability in der Kontrollgruppe von 4 von 4 reduzierte sich auf 2 von 4 in der Ethanolgruppe.

3.5 Schlussfolgerungen

Für die Entwickler chirurgischer VR-Trainingssysteme bedeuten die in dieser Arbeit gewonnenen Erkenntnisse zu **Ziel 1**, dass durch eine sorgfältig gestaltete VR-Umgebung, die der Benutzer als besonders ansprechend empfindet, die User Experience und Usability eines chirurgischen VR-Trainingssystems gesteigert werden kann. Dies könnte auch den Lernerfolg positiv beeinflussen, da positive Emotionen zu einem schnelleren Erreichen des Lernziels beitragen können [96]. Im Umkehrschluss lassen die Ergebnisse darauf schließen, dass auch ein technisch gutes chirurgisches VR-Trainingssystem aufgrund einer schlechten Presence von den Chirurgen abgelehnt wird bzw. zu schlechteren Lernergebnissen führen könnte.

Die Ergebnisse zu **Ziel 2** implizieren, dass Produktevaluationen nur nach sorgfältiger Vorbereitung der Studienumgebung durchgeführt und unter Berücksichtigung der Presence ausgewertet werden sollten. Die virtuelle Evaluationsumgebung sollte sämtliche relevante Eigenschaften des Produktes in allen Wahrnehmungsmodalitäten (z.B. visuell, auditiv, olfaktorisch, haptisch) möglichst realistisch simulieren, um weder ein positives noch negatives Bias in die Evaluationsergebnisse einfließen zu lassen. Zusammenfassend lässt sich feststellen, dass die Probanden zwischen der Bewertung des Produktes und der VR-Umgebung mit den gegenwärtig genutzten Evaluationsinstrumenten nicht unterscheiden und beides zusammen bewerten.

Die Ergebnisse zu **Ziel 3** legen nahe, dass es bereits bei einem verhältnismäßig niedrigen Blutalkoholspiegel zu einer Entkopplung der Zusammenhänge von Presence und User Experience kommen kann. Die Ergebnisse geben zudem einen ersten Einblick in unterbewusste, äußerlich schwer feststellbare Effekte von Ethanol während einer VR-Erfahrung. Diese Befunde liefern erste Hinweise, dass auch der Entscheidungsfindungsprozess verändert sein kann, bzw. die Art, wie Probanden über ihre VR-Erfahrung berichten. Diese Veränderung beeinflusst allerdings nicht die Entscheidung selbst, möglicherweise aber die ins Bewusstsein gelangende Entscheidungsgrundlage. In Bezug auf VR-Trainingssysteme könnten zudem bereits niedrige Ethanolmengen den positiven Effekt der Presence auf den Lernerfolg ausschalten, da hierdurch die bestehenden Zusammenhänge zwischen Presence und User Experience minimiert werden.

Die vorliegenden Ergebnisse bieten somit eine Grundlage, VR-basierte Anwendungen als Training oder Produktevaluation in der Orthopädie und Unfallchirurgie zu verbessern. Die Befunde lassen zudem den Schluss zu, dass für die bestehenden Instrumente zur Betrachtung von Presence, User Experience und Usability ein erheblicher Bedarf der Verfeinerung und Weiterentwicklung besteht.

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III Darstellung des eigenen Beitrags

Nachfolgend erfolgt per Unterschrift durch den Promovenden, Herr Mario Lorenz, der auch bei allen Publikationen korrespondierender Autor ist und mindestens der Hälfte der Co-Autoren die Bestätigung der ausgeführten inhaltlichen Spezifizierung des jeweilig geleisteten Beitrags zur Erstellung und Abfassung der Publikationsschriften.

Brade, J., Lorenz, M., Busch, M., Hammer, N., Tscheligi, M., & Klimant, P. (2017). **Being there again – Presence in real and virtual environments and its relation to usability and user experience using a mobile navigation task.** *International Journal of Human-Computer Studies*, *101*, 76–87. https://doi.org/10.1016/j.ijhcs.2017.01.004

Inhaltlich geleisteter Beitrag für den oben genannten Artikel des Promovenden, Herr Mario Lorenz:
Partizipation an der Konzeption und dem Design der Forschungsfragen sowie der technischen Implementierung der Studienumgebung, Literaturrecherche, Diskussion, Verfassung des Manuskripts, Koordination des Publikationsprozesses

Wir bestätigen hiermit den oben beschriebenen geleisteten Beitrag durch Herrn Mario Lorenz:

…………………………………………………………………	…………………………………………………………………
Prof. Dr. Niels Hammer	Dr. Philipp Klimant
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M. Sc. Jennifer Brade	M. Sc. Mario Lorenz

Lorenz, M., Brade, J., Diamond, L., Sjölie, D., Busch, M., Tscheligi, M., Klimant, P., Heyde, C.-E. & Hammer, N. (2018): **Presence and User Experience in a Virtual Environment under the Influence of Ethanol. An Explorative Study.** In: Scientific reports 8 (1), S. 6407. DOI: 10.1038/s41598-018-24453-5.

Inhaltlich geleisteter Beitrag für den oben genannten Artikel des Promovenden, Herr Mario Lorenz: Konzeption und Design der Forschungsfragen, Partizipation bei der Erstellung des Studiendesigns und der technischen Implementierung der Studienumgebung sowie der Studiendurchführung, Literaturrecherche, Auswertung der Daten, Diskussion, Verfassung des Manuskripts, Koordination des Publikationsprozesses

Wir bestätigen hiermit den oben beschriebenen geleisteten Beitrag durch Herrn Mario Lorenz:

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Prof. Dr. Christoph-E. Heyde

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Prof. Dr. Niels Hammer

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Dr. Philipp Klimant

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M. Sc. Jennifer Brade

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M. Sc. Mario Lorenz

IV Erklärung über die eigenständige Abfassung der Arbeit

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und ohne unzulässige Hilfe oder Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Ich versichere, dass Dritte von mir weder unmittelbar noch mittelbar eine Vergütung oder geldwerte Leistungen für Arbeiten erhalten haben, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen, und dass die vorgelegte Arbeit weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde zum Zweck einer Promotion oder eines anderen Prüfungsverfahrens vorgelegt wurde. Alles aus anderen Quellen und von anderen Personen übernommene Material, das in der Arbeit verwendet wurde oder auf das direkt Bezug genommen wird, wurde als solches kenntlich gemacht. Insbesondere wurden alle Personen genannt, die direkt an der Entstehung der vorliegenden Arbeit beteiligt waren. Die aktuellen gesetzlichen Vorgaben in Bezug auf die Zulassung der klinischen Studien, die Bestimmungen des Tierschutzgesetzes, die Bestimmungen des Gentechnikgesetzes und die allgemeinen Datenschutzbestimmungen wurden eingehalten. Ich versichere, dass ich die Regelungen der Satzung der Universität Leipzig zur Sicherung guter wissenschaftlicher Praxis kenne und eingehalten habe.

Chemnitz, 16.10.2019 ……………………………………………………………………

M. Sc. Mario Lorenz

V Wissenschaftliche Veröffentlichungen und Vorträge

Journal Publikationen

Brade, Jennifer; Lorenz, Mario; Busch, Marc; Hammer, Niels; Tscheligi, Manfred; Klimant, Philipp (2017): Being there again - Presence in real and virtual environments and its relation to usability and user experience using a mobile navigation task. In: International Journal of Human-Computer Studies 101, S. 76-87. DOI: 10.1016/j.ijhcs.2017.01.004.

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Reviewing-Tätigkeiten

Journal of Medical Internet Research

The ACM conference on Designing Interactive Systems (DIS) 2019

IEEE Virtual Reality Conference 2019

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