Distance Estimation in Virtual Environments: Problems and Solutions

A State-of-the-Art Protocol

# Introduction

* Anwendungsfelder
  + Architektur
  + Rehabilitation
    - Thomas2016
* Problematik
* Systematik der Papersuche
* Systematischer Aufbau des Papers
* Perceiving 3D shape and layout is a classic example of an ill-posed and underconstrained inverse problem (Vision in 3D environments, Buch-PDF)
  + Underconstrained: a unique solution is not obtainable from visual input
  + Ill-posed: small changes in the input can lead to significant changes in the output
    - Vulnerable to noise

# Measurement Methods

* While distances are underestimated independently of the applied measurement method, the amount of the underestimation can differ between measurement methods
* Effect of an experimental manipulation might be found with one but not with another measurement method

## Verbal Estimates

* Objects still available
* Close their eyes first
* Close their eyes and turn the head first

## Perceptual Matching

* Indicate the midpoint

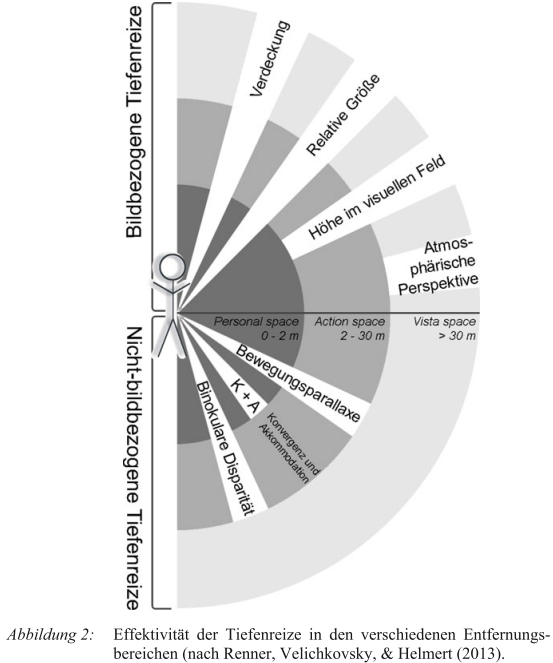
## Visually Directed Actions

* Blind Walking
  + Generally, more accurate than those obtained via triangulated blind walking or indirect blind walking
* Blind Treadmill Walking
* Triangulated Blind Walking
* Indirect Triangulated Blind Walking
* Timed Imagined Walking

# Distance Perception in Real World

## Psychophyik

* Cutting and Vishton
  + Kein anderes Wahrnehmungssystem arbeitet mit so vielen Informationsquellen für ein Problem, die visuelle Raumwahrnehmung
  + Near-veridical
  + Perceptual spaces are sufficiently close to Euclidean
  + We appear to have rough metric knowledge in making distance judgements, on the other hand, do not appear to improve with feedback
  + “Reasonable accuracy”
    - 0,78-1,22, mean 0,95 (Cook 1978)
    - 0,60-1,30, mean 0,94 (Wohlwill, 1964)
  + Egocentric depth is systematically foreshortened when compared to frontal depth (verbal?)
    - 10 -> 9
    - 100 -> 79
    - 1000 -> 710
  + Blind walking doesn´t show foreshortening
    - Thomson 1980
    - Laurent and Cavallo 1985
    - Rieser et al. 1990 “Visual perception and the guidance of locomotion without vision to previously seen targets”
  + Direkter Vergleich in Loomis et al. 1992
  + Foreshortening tritt auch nur auf, wenn Person sich nicht bewegen darf (Wagner 1985)
  + Mehr Tiefenreize:
    - Mehr Tiefe
    - Höhere Konstanz und Genauigkeit
  + Hohe Varianz in der Nutzung von Stereopsis zwischen den Teilnehmern, bei keinem anderen Tiefenreiz so stark
  + Distance perception nearly 100% of actual distance
    - Loomis and Knapp 2003 (Kelly2014)
  + Personal space (<2m)
    - Occlusion (constant)
    - Retinal disparity (decline)
    - Relative size (constant)
    - Convergence (decline)
    - Accommodation (decline)
    - Motion information (decline)
  + Action Space (<30m)
    - Occlusion (constant)
    - Height in visual field (decline)
    - Binocular disparity (decline)
    - Motion perspective (decline)
    - Relative size (constant)
  + Vista Space (>30m) (pictorial cues)
    - Occlusion
    - Height in visual field
    - Relative size
    - Aerial perspective



## Auswahl an Studien

* Loomis et al. 1992 (Leyrer2015)
* Rieser et al. 1995 (Leyrer2015)
* Grechkin et al. 2010 (Leyrer2015)
* Cutting1995 (Piryankova2013)
* Loomis2002 (Piryankova2013)
* Kuhl2006 (Piryankova2013)
* Richardson2005 (Piryankova2013)
* Vertical distances viewed from the top are often overestimated [25](Marsh2014)
* Large heights are also overestimated from the bottom, though to a lesser degree [25] (Marsh2014)
* When observing a frontal view of an object, vertical distances are often overestimated by 10-15% relative to horizontal distances [25] (Marsh2014)
* These biases may be moderated by an individual´s fear of heights [18] (Marsh2014)
* Verbale Einschätzung:
  + Kleine Entfernungen relative genau
  + Größere Entfernungen unterschätzt
  + Loomis and Philbeck 2008 (Renner2014)
* Near to veridical with blind walking up to 20m in RW
  + Loomis 2008 (Kelly2014)
  + Jones2013 (Kelly2014) “Peripheral stimulation and its effect on perceived spatial scale in VEs”
* Entfernungen bis 25 m relative genau eingeschätzt
  + Loomis and Philbeck 2008 (Renner2014)
* Exocentric distances oriented in the frontal plane have been found to be overestimated more than those in the depth plane (Geuss2013)
* Piryankova2013
  + Im Vergleich mit LSIDs
    - Verbal und blind walking
    - Für das verbale könnte das an der Nutzung von Meter statt Feet liegen, in anderen Studien kam es zu Unterschätzungen:
      * Plumert2005
      * Klein2009
      * Grechkin2010
      * Mohler2006
    - Auch die relativ geringe Distanz (bis 6m) könnte Grund sein
  + Accuracy of the distance judgements in both the real and the virtual world are influenced by the distance to the target

# Distance Perception In VR

* Einleitung
  + Distance and size perception are often biased in such environments, causing users to overestimate or underestimate spatial relations (Interrante2008, Lindquist and Anderson 2007, Loomis and Knapp 2003) (Bruder2016)
* Für einen allgemeineren Vergleich von der Performance mit 2D- und 3D-Displays siehe McIntire2014
* Distances are linearly compressed in VEs relative to corresponding estimates in the real world [13] by up to about 50% [12] (Marsh2014)
* As in the real world, depth spans are often compressed relative to frontal spans [10] (Marsh2014)
* Fink et al. [5] showed differences in trajectories between real and virtual movements, indicating greater uncertainty about object positions
* Interfaces for large-scale virtual locomotion often do not allow for the types of body-based translation movements, such as walking, that may lead to construction of accurate spatial representations [17] (Marsh2014)
* Waller2008 (Kelly2014)
  + Review of past research (variety of display technologies and VEs)
  + Distances in VEs are perceived to be just 71% of the intended distance, on average
  + Differences across individuals and across studies resulted in a 95% confidence interval of +/-8,2%
* Similar results with
  + Blind throwing
    - Eby and Loomis 1987 (Kelly2014) “A study of visually directed throwing in the presence of multiple distance cues”
    - Ooi et al. 2001 (Kelly2014) “Distance determined by the angular declination below the horizon”
  + Imagined walking
    - Grechkin2010 (Kelly2014)
* Precision decreases approximately linearly with object distance
  + Rieser et al. 1990 (Kelly2014) “Visual perception and the guidance of locomotion without vision to previously seen targets”
* Ergebnisse der Studien mit Tiefenreizen spiegeln hoffentlich die aus RW wider

## Experimental Factors

### Egocentric Spaces

#### Personal Space

* Reaching/Pointing
* Verbal estimates?
* Thomas2016
  + Full-body reaching tasks
    - 1) HMD (1st-person perspective)
    - 2) 3D-Display ( 3rd-person perspective)
    - 3) real world
  + joint excursions are dependent on the environment
  + Der Vergleich hinkt schon sehr, da 2) und 3) sich in zu vielen Punkten unterscheiden und damit die Ursache vollkommen unklar bleibt
* CampbellStewart2013 “Planning and Adjustments for the Control of Reach Extent in Virtual Environment”
  + VE did not impact movement planning or subsequent compensatory adjustments for the control of reach extent when directly compared to an analogous RWE
  + (nur Armbewegung, Bildschirm ähnlich wie bei unserem Schuhmodell)
* Schafer2013
  + 3 angles:
    - 10° above horizon (resembling RW viewing angle)
    - 50° above horizon
    - 90° above horizon (directly overhead)
  + All participants reached ca. 9% farther in 50° condition than in RW
  + 9-10% less in 10° condition than in RW
  + Virtual reaches had smaller velocity peaks and took longer than physical reaches
  + Results suggest that visual perception in the VE differs from RW perception
  + performance of functional tasks can be changed in TBI patients, depending on the viewing angle
  + viewing angle is a critical parameter that should be adjusted carefully to achieve maximal therapeutic effect during practice in the VE
  + (ganzer Oberkörper wird mitbewegt, großer 3D-TV)

#### Action Space

#### Vista Space

* Bruder 2016 zählt folgende Paper auf:
  + Alexandrova et al 2010
  + Grechkin et al. 2010
  + Klein et al. 2009

### Measurement Methods

* Often misperceived in VR regardless of the measure used:
  + Loomis and Knapp 2003 (Leyrer2015)
  + Thompson et al. 2004 (Leyrer2015)
  + Sahm et al. 2005(Leyrer2015)
* Action-based distance judgements produce more accurate responses than verbal judgements, which tend to result in underestimation
  + Loomis and Philbeck 2008 (Kelly2014)

#### Verbal Estimates

* Kunz et al. 2009 (Leyrer2015)
* Mohler et al. 2006 (Leyrer2015)
* Kunz2009 (Piryankova2013)
* Klein2009 (Piryankova2013)
* Piryankova2013
* In RW:
  + Kleine Entfernungen relative genau
  + Größere Entfernungen unterschätzt
    - Liegt wahrscheinlich an der Unterschätzung der metrischen Skala und nicht des Raums
      * Plumert2005 (Piryankova2013)
      * Mohler2006 (Piryankova2013)
  + Loomis and Philbeck 2008 (Renner2014)

#### Perceptual Matching

* Relative Schätzung der Distanz (Renner2014)
* Proband gleicht Entfernung zu einem Objekt an eine Vergleichsentfernung an oder teilt eine Entfernung in zwei gleich große Hälften (Renner2014)
* Relativ gute Schätzung in RW:
  + Creem-Regehr and Kunz 2010 (Renner2014) „Perception and Action “
  + Rieser et al. 1990 (Renner2014) „Visual perception and the guidance of locomotion without vision to previously seen targets “
  + Proffitt 2006 (Renner2014) „Distance Perception“
* Renner2014
  + Größenanpassung: virtueller Kegel in bestimmter Entfernung sollte gleich groß sein wie realer Kegel

#### Visually Directed Actions

##### Throwing

* Wahn et al. 2005 (Leyrer2015)
* Geuss2013

##### Blind Walking

* Thompson et al. 2004 (Leyrer2015)
* Geuss2013
* Grechkin et al. 2009 (Leyrer2015)
* Direct
  + Plumert2005 (Piryankova2013)
  + Grechkin2010 (Piryankova2013)
  + Kunz2009 (Piryankova2013)
  + Loomis et al. 2002 (Piryankova2013)
  + Kuhl et al. 2006 (Piryankova2013)
    - Analysis of direct blind walking in RW
      * Up to 12m
      * On average accuracy 96%
      * Their research suggests that the variability of the performance of individuals in direct blind walking does not require many participants, but cautioned that even without feedback people become more accurate at performing the task over time
      * This could be due to the increased familiarity of walking with closed eyes over time
        + Philbeck1997
  + Interrante2008 (Piryankova2013)
  + Willemsen2008 (Piryankova2013)
* Triangulated
  + Klein2009 (Piryankova2013)
  + Riecke2009 (Piryankova2013)
  + Thompson2004 (Piryankova2013)
* Imagined timed walking
  + Plumert2005 (Piryankova2013)
  + Klein2009 (Piryankova2013)
  + Grechkin2010 (Piryankova2013)
* Klein2009 (Piryankova2013)
  + Suggests that action-based response measures performed in small spaces are likely to result in underestimation of distances, due to insufficient space to perform

### Egocentric/Exocentric (Depth/Frontal Plane)

* Geuss2013
  + Perceived absolute distance in a HMD-VE and a matched RW environment
  + Exp1:
    - Egocentric distances
    - Blind walking
    - Egocentric underestimated
    - Exocentric estimated similarly to RW
    - -> related to orientation or type of distance
  + Exp2:
    - Exocentric distances presented along the depth or frontal plane
    - Blind walking
  + Exp3:
    - Exocentric distances presented along the depth or frontal plane
    - Bean bag throwing
  + Both show underestimation of depth intervals and veridical estimation of frontal intervals (zweiter Teil repliziert Studie von Geuss et al. 2010)
  + Findings suggest anisotropy in HMD-VE distance perception

### Others

* Zusammen mit der Studie von Klein2009 (1,22m viewing distance) und hier 0,83m viewing distance scheint die Entfernung zur Leinwand Einfluss zu haben (Piryankova2013)
* Empfehlungen für Experimente: (Piryankova2013)
  + RW als Kontrollbedingung, virtuelle Replikation des Raums
  + Große Auswahl an Distanzen, um deren Effekt mit in Betracht zu ziehen

## Technical Factors

### Type of Display

* Unterschätzung tritt bei allen Displaytypen auf

#### Computer Screen

#### Large flat screen

* Piryankova et al. 2013 (Bruder2016)
  + Underestimation
  + Interaction effect with the distance to the displayed target
* Entfernungen vor Leinwand überschätzt, hinter Leinwand unterschätzt (Renner2014)

#### CAVE

* Bruder2016 “CAVE Size Matters: Effects of Screen Distance and Parallax on Distance Estimation in Large Immersive Display Setups”
  + distance estimation dependent on distance towards screens and parallax
  + increased underestimation for positive parallax
  + slight overestimation for negative and zero parallax
  + space is most important characteristic for distance perception, optimally requiring about 6-7m distance around the user
  + no difference between medium- and high-resolution
* Marsh2014
  + in a CAVE, it is usually possible to see corners where the screens meet.
  + In addition, optical accommodation can inform the user about screen position and orientation [21]
  + It is conceivable that a user, particularly one with a relatively low level of virtual presence, may use these physical aspects when judging virtual distances
  + Exp1:
    - Hypotheses:
      * Ability to locomote may help users judge distances by maneuvering to the optimal vantage point(s)
      * using a handheld wand may lead to greater underestimation, particularly on vertical spans, due to the ease of travel
    - statistically, horizontal estimates were veridical
    - underestimation of analogous vertical spans that has not been previously explored in the literature (in RW overestimation)
    - because estimates were more accurate with the Flystick interface, these results fail to support the notion that less-effortful locomotion causes underestimation
    - these results do indicate that the ability to interact improves distance estimates
    - many results not statistically significant
  + Exp2:
    - Hypothesis:
      * Distance judgements on the plane of the physical floor or walls of the CAVE would be more accurate than those in purely virtual space
    - Some underestimation of horizontal spans
    - Significant differences between positions reflect better performance when cones were positions along the CAVE corners than when cones were behind the physical screen or co-planar with a single physical wall
      * Users could make use of information from the physical environment to aid in distance estimation, and this helped equally on the vertical and horizontal judgements
      * This only happened when cones were placed on a single wall or the floor
  + Observations and performance patterns also indicated that participants attempted to use the physical CAVE boundaries when learning distances
  + Users know where the physical projection surfaces are
  + Assumption: users had a low level of presence in VE
  + Increased virtual presence could cause users to neglect the physical cues in favor of purely virtual judgements, should be further explored

#### MPI cabin

* In MPI cabin opposite trend (Piryankova2013)
  + Shape of cabin
  + Non-stereoscopic projection
  + Constantly changing position with respect to the physical projection surface

#### HMD

* Ergonomics of HMD
  + Willemsen2009
* Restricted field of view
  + Knapp and Loomis 2004 (Leyrer2015) (Kelly2014)
  + Creem-Regehr et al. 2005 (Leyrer2015) (Kelly2014)
  + Jones et al. 2013 (Leyrer2015) compared 150° with 60° -> significant improvement, albeit still underestimated
  + Willemsen2009 (Kelly2014)
* White light in the periphery
  + Jones, Swan, Bolas 2013 (Kelly2014) “Peripheral stimulation and its effect on perceived spatial scale in VEs”

### Nonpictorial Depth Cues

* Willemsen et al. 2008 (Leyrer2015) (Kelly2014)
* Stereoskopische Darstellung verbessert Entfernungseinschätzungen für nahe Entfernungen
  + Bingham et al. 2001 (Renner2014) „Accomodation, occlusion, and disparity matching are used to guide reaching: A comparison of actual vs. virtual environments “
  + Luo et al. 2009 (Renner2014) “On the Determinants of Size Constancy in a Virtual Environment” (keine PDF gefunden)
  + Widersprüchliche Ergebnisse (Renner2014)
    - Bruder et al. 2012 “Analyzing effects of geometric rendering parameters on size and distance estimation in on-axis stereographics”
    - Kellner et al. 2012 „Geometric Calibration of Head-Mounted Displays and its Effects on Distance Estimation. “
    - Willemsen et al. 2008

#### Motion Parallax

* Scheint keinen Einfluss zu haben
  + Beall et al. 1995 (Renner2014) “Absolute motion parallax weakly determines visual scale in real and virtual environments”
  + Luo et al. 2009 (Renner2014) “On the Determinants of Size Constancy in a Virtual Environment” (keine PDF gefunden)

#### Convergence/Accommodation

* Hoffman et al. 2008 (Bruder2016)
* Provide distance cues up to a distance of about 6 meters
  + Creem-Regehr et al. 2005
  + Cutting1995
  + Willemsen2008
  + (Bruder2016)
* Convergence:
  + When focusing on an object, the eyes need to rotate toward that object to bring it to the fovea of each retina (Bruder2016)
  + The convergence state of the eyes, changed by extrinsic muscle exertion, provides an absolute cue about the distance to an object (Bruder2016)
  + Formel dazu siehe Bruder2016
* Accommodation:
  + When an object is fixated by the eye, the ciliary muscles are adjusted such that a sharp image is perceived on the retina (Bruder2016)
  + The state of the ciliary muscles provides an absolute cue about the distance to the focused object (Bruder2016)
  + Differ between fuzzy and high-contrast stimuli (Fisher and Ciuffreda 1988 (Bruder2016))
  + While accommodation can be leveraged as a distance cue, the influence of the accommodative information declines with
    - Age (Oierscionek 1993 (Bruder2016))
    - Distance (Cutting and Vishton 1995 (Bruder2016))
    - Decreasing cue reliability (Hoffman et al. 2008 (Bruder2016))
* In stereoscopic display systems, the observer accommodates to the distance of the display surface to perceive objects without blur, whereas the convergence angle depends on parallax (Bruder2016)
* Convergence cue -> distance to virtual object (Bruder2016)
* Accommodation -> distance to physical screen (Bruder2016)
* Three parallax conditions are considered
  + Negative parallax -> object in front of the display
  + Zero parallax -> object on the display
  + Positive parallax -> object behind the display
  + Bourke 1999 (Bruder2016)
* Negative or positive parallax -> conflicting depth information (Drascic and Milgram 1996 (Bruder2016))
* Bruder2016:
  + Participants were significantly more accurate at zero parallax than for objects displayed with positive parallax
  + Only a trend for a difference between negative and zero parallax
  + Participants on average overestimated distances to objects with negative parallax
  + showed and underestimation for longer distances
  + underestimation for positive parallax
  + The magnitude of underestimation was higher than that of the observed overestimation
  + Possible explanations
    - Accommodation/convergence mismatch
    - Longer screen distances -> accommodation cue weaker
    - Changes of angular resolution may explain some of the observed underestimation
      * A low angular resolution may act as an artificial cut-off to binocular distance cues and may reduce accommodation responses
      * The closer the user is to the screen, the lower is the angular resolution
    - Retinal size of the virtual stimuli is proportional to the screen distance and inversely proportional to the target distance
      * Objects at negative parallax take up a larger screen space on the projection wall than objects at positive parallax
    - Sparse depth cues in the visual stimuli in controlled experiment might have reduced overall precision in distance judgements, and peripheral vision of bezels of the projection setup might have had an additional effect on the results
  + Second experiment, doubled angular resolution
    - Did not remedy distance underestimation
    - Judgements not improved
    - It appears unlikely that a resolution with full visual acuity due to ultra-high resolution displays would result in veridical distance perception
    - Different retinal sizes did not have a string effect on absolute or relative distance estimation
    - No significant difference in distance estimation due to a checkerboard pattern on the target objects
      * Expected the checkerboard pattern to provide more luminance differences and thus enable improved accommodation responses, which in turn should consolidate the accommodation-convergence conflicts
      * Results suggest that accommodation responses might have generally been quite good
  + In summary
    - Distance underestimation not directly result of
      * Resolution
      * Plain target stimuli
      * Retinal size
      * Peripheral vision of the bezels of the projection screens
    - Screen distance and parallax -> main factors affecting distance estimation to targets up to 9m
    - (in reduced-cue environments)
    - Recommend 6-7m space around
* Sich widersprechende Entfernungsinformationen sind eine Schwierigkeite für gute Entfernungswahrnehmung
  + Bingham et al. 2001 (Renner2014) „Accomodation, occlusion, and disparity matching are used to guide reaching: A comparison of actual vs. virtual environments “
  + Drascic and Milgram 1996 (Renner2014) „Perceptual Issues in Augmented Reality “

#### Binocular Disparity / Stereopsis

* 2 views of a scene from laterally separated positions at a fixed interpupillary distance (IPD) (Bruder2016)
* Stereobasis hatte keinen relevanten Einfluss (Renner2014)
  + Überraschend, siehe Drascic and Milgram 1996 (Renner2014)
  + Möglicherweise Messmethode nicht sensitiv genug (Renner2014)
* Stereoscopic projection significantly impacts distances up to 2,5 m, but still underestimation (Piryankova2013)
* Even when providing both stereoscopic projection and motion parallax, participants in the flat LSID significantly underestimated distances compared to RW (Piryankova2013)

### Geometric Distortions

* Kuhl et al. 2009 (Leyrer2015, Renner2014)
* Bruder et al. 2012 (Renner2014) “Analyzing effects of geometric rendering parameters on size and distance estimation in on-axis stereographics”
* Leyrer et al. 2011 (Renner2014) “The influence of eye height and avatars on egocentric distance estimates in immersive virtual environments”

#### Minification/Magnification

#### Distorted Angle of Declination

#### Deviating Stereo Base

#### Pincushion Distortion

### Quality of Graphics

* Thompson et al. 2004 (Leyrer2015), (Kelly2014), (Piryankova2013)
* Kunz et al. 2009 (Leyrer2015), (Piryankova2013)
  + the quality of computer graphics (in terms of providing a rich VE containing realistic textures and materials) has no impact on direct blind walking but it does inﬂuence verbal reports of egocentric distances (aus Piryankova2013)

#### Resolution

* Bruder 2016 “CAVE Size Matters: Effects of Screen Distance and Parallax on Distance Estimation in Large Immersive Display Setups”
  + no difference between medium- and high-resolution

#### Photoreality

## Virtual Environmental Factors

### Pictorial Depth Cues

* Einschätzung wird besser, je mehr Reize zur Verfügung stehen
  + Kenyon et al. 2007 (Renner2014) „Size-Constancy in the CAVE “
  + Murgia 2009 (Renner2014)
  + Sinai et al. 1999 (Renner2014) “Egocentric distance perception in a virtual environment using a perceptual matching task”
* Keine Tiefenreize (Objekt auf Augenhöhe vor weißem Hintergrund) -> größte Abweichungen (Renner2014)
* Bedeutung von Höhe im visuellen Feld als Tiefenreiz auch für VE (Renner2014)
* Nutzen einer regelmäßigen Bodentextur zeigte sich nur für Entfernungen hinter der Leinwandebene (Renner2014)
  + Hebt Mehrdeutigkeit auf (Objekt weit weg oder auf anderer Höhe) (Renner2014)
* Darstellung einer zusätzlichen komplexen Szene hatte keinen Effekt (Renner2014)
  + Möglicherweise Abstand Zielobjekt/Wände zu groß (Renner2014)

### Adding Avatars

* Ries et al. 2008 (Leyrer2015)
* Mohler et al. 2008 (Leyrer2015)
* Mohler et al. 2010 (Leyrer2015)

### Adding Ground Texture

* In realen Umgebungen ist eine kontinuierliche und einheitlich texturierte Bodenfläche für exakte Entfernungswahrnehmung notwendig
  + He et al. 2004 (Renner2014) „“
  + Sinai et al. 1998 (Renner2014) “”
  + Wu et al. 2004 (Renner2014) “”

(alle im gleichen Team)

* In VR widersprüchliche Ergebnisse (renner2014)
  + Kenyon et al. 2007 „Accommodation and Size-Constancy of Virtual Objects. “
  + Kenyon et al. 2007 “Size-Constancy in the CAVE®.”
  + Luo et al. 2009 “On the Determinants of Size-Constancy in a Virtual Environment. “
  + Sinai et al. 1999 “Ego-centric distance perception in a virtual environment using a perceptual matching task.”
  + Witmer and Kline 1998 “Judging perceived and traversed distance in virtual environments”

### Adding Objects with Familiar Size

### Environment

* Beschaffenheit der Umgebung hinter dem Zielobjekt hat Einfluss
  + Witt et al. 2007 (Renner2014) „{Seeing beyond the target: Environmental context affects distance perception“
* Unterschiede zwischen innen und außen:
  + Lappin et al. 2006 (Renner2014) “Environmental context influences visually perceived distance”

#### Indoor

#### Outdoor

### Virtual Replicas

* Bessere Einschätzung
  + Interrante et al. 2006 (Renner2014) “Distance Perception in Immersive Virtual Environments, Revisited.”
  + Steinicke2010 (Renner2014)

### Transitional Environments

* Environments, participants never experienced
  + Interrante, Anderson, Ries 2006 (Kelly2014) “Distance perception in Immersive Virtual Environements, Revisited”
* Virtual replica
  + Steinicke et al. 2009 (Kelly2014) “Presence-enhancing real walking user interface first-person video games”
  + Steinicke2010 (Kelly2014)
  + Steinicke et al. 2009 (Kelly2014) “Does the gradual transition to the virtual world increase presence?”

### Others

* Witt2007 (Piryankova2013)
  + demonstrates that distance perception in the real world is inﬂuenced by the layout of the space beyond the viewed target. More speciﬁcally, individuals tend to slightly overestimate the distance between themselves and the target when the target was placed near the end of a hallway, while the distance estimates to a target placed far from the end of the hallway were underestimated

## Human Factors

### Presence

* Interrante 2008 (Kelly2014)(Piryankova2013)
* Interrante, Anderson, Ries 2006 (Kelly2014, Renner2014) “Distance perception in Immersive Virtual Environements, Revisited”
* Mohler et al. 2008 (Renner2014) “A full-body avatar improves egocentric distance judgments in an immersive virtual environment.”
* Steinicke2010 (Renner2014)

### Influence of Feedback and Practice

* Kelly2014 “Recalibration of Perceived Distance in VEs Occurs Rapidly and Transfers Asymmetrically Across Scale”
  + how quickly occurs improvement of perceived distance as a result of walking
  + influence of walked distance
  + brief period of interaction by walking through the virtual environment with visual feedback can cause dramatic improvement in perceived walking
  + 5 interaction trials resulted in a large improvement in perceived distance
  + subsequent walking interactions showed continued but diminished improvement
  + interaction with near objects (1-2m) improved distance perception for near but not for far objects (4-5m)
  + interaction with far objects broadly improved distance perception for both
* interaction with the virtual environment by walking with visual feedback has recently been shown to drastically improve perceived distance to within 90-100% of actual distance with sufficient interaction
  + Kelly2014
    - Waller2008
      * 1-4m (Kelly2014)
      * 50% pre-interaction -> 100% post-interaction (Kelly2014)
    - Mohler et al. 2006 “The influence of feedback on egocentric distance judgements in real and virtual environments”
      * 3-7m (Kelly2014)
      * 70% -> 90% (Kelly2014)
    - Richardson and Waller 2005 “The effect of feedback training on distance estimation in VEs”
    - Richardson and Waller 2007 “Interaction with an immersive virtual environment corrects user´s distance estimates”
* Kelly et al. 2013 (Kelly2014) “More than just perception-action recalibration: …”
* Mohler et al. 2006 (Leyrer2015), (Piryankova2013)
* Richardson and Waller 2007 (Leyrer2015), (Piryankova2013)
* Waller and Richardson 2008 (Leyrer2015, renner2014)
* Walking interaction has similar effects on blind walking judgements and size judgements
  + Kelly et al. 2013 (Kelly2014) “More than just perception-action recalibration: …”
* Interrante et al. 2006 (Renner2014)
* Korrigierendes Feedback wird empfohlen:
  + Mohler2007 (Piryankova2013)
  + Richardson2005 (Piryankova2013)

### Interindividual Differences

# Transfer Effects

* Waller and Richardson 2008 (Leyrer2015)

# Others

* Paquier 2016 “Interaction Between Auditory and Visual Perceptions on Distance Estimations in a VE”
  + Even though egocentric distance was underestimated in all contexts, the results showed a higher influence of visual information than auditory information on the perceived distance.
  + Specifically, the bimodal incoherent condition gave perceived distances equivalent to those in the visual-only condition when the visual target was closer to the subject than the auditory target.
* Grechkin 2016 “Dynamic Affordance in Embodied Interactive Systems: The Role of Display and Mode of Locomotion”
  + Mode of locomotion, but not type of display, affected how participants chose opportunities for action
  + Both mode of locomotion and display affected performance when participants acted on their choices
* CampbellStewart2013 “Planning and Adjustments for the Control of Reach Extent in Virtual Environment”
  + VE did not impact movement planning or subsequent compensatory adjustments for the control of reach extent when directly compared to an analogous RWE
  + (nur Armbewegung, Bildschirm ähnlich wie bei unserem Schuhmodell)
* Schafer2013
  + 3 angles:
    - 10° above horizon (resembling RW viewing angle)
    - 50° above horizon
    - 90° above horizon (directly overhead)
  + All participants reached ca. 9% farther in 50° condition than in RW
  + 9-10% less in 10° condition than in RW
  + Virtual reaches had smaller velocity peaks and took longer than physical reaches
  + Results suggest that visual perception in the VE differs from RW perception
  + performance of functional tasks can be changed in TBI patients, depending on the viewing angle
  + viewing angle is a critical parameter that should be adjusted carefully to achieve maximal therapeutic effect during practice in the VE
  + (ganzer Oberkörper wird mitbewegt, großer 3D-TV)

# Solution Approaches

* To facilitate distance perception as well as possible, it is important to [Renner2013]
* provide binocular disparity,
* use high quality of graphics,
* carefully adjust the virtual camera settings,
* display a rich virtual environment
  + containing a regularly structured ground texture,
* and enhance the user´s sense of presence.
* Calibration / Setting
* Complex environment
* Practice and Feedback
* …
* Minification
  + Kuhl et al. 2009 (Leyrer2015)
  + Influences verbal report and blind-walking differently (Zhang et al. 2012 (Leyrer2015))
* Tilting
* Eye-Height Manipulation (+/- 50cm)
  + Has predictable effects on action-based and cognitive measures of egocentric distance
  + Simple EHM can be used to selectively alter perceived distances on an individual basis, which could be helpful to enable every user to have an experience close to what was intended by the content designer
  + Exp1:
    - Erkundungsphase in VR für 5 min, nur Kopfbewegung
    - Sparse-cue environment (SCE) / rich-cue environment (RCE) -> familiar size-cues
    - Walked distances in RCE greater
    - EHM had strong effect
    - EHM influences perceived distances differently, depending on environment
  + Exp2 (SCE):
    - individual EHM
    - EHM had significant effect
    - Berechnung geht auf
    - Keiner nahm Manipulation wahr
    - Starke Varianz zwischen Teilnehmern (70-90% der eigentlichen Entfernung wahrgenommen)
  + Exp3 (RCE):
    - Same setup as in Exp2
    - Mean walked distance ratios are overall better than in SCE
    - Already close to RW
    - Improvement with EHN
    - No partipicant recognized EHM
    - Presence of additional cues has impact on estimated distance
    - Amount of EHM is less
    - Overwalking observed -> EHM also effective
  + Exp4:
    - Same setup as in 2 and 3
    - Extended distance (multiplicative prediction)
    - SCE: walked significant farther with EHM
    - RCE:
    - Both close to RW, but not as far as intended
    - Possible reasons:
      * Manipulation has different effects on participants in both environments
      * Manipulation too large
        + Several participants noticed manipulation
        + Limitations
      * Anfängliche Augenhöhe nicht für Teilnehmer angepasst
      * Durchschnittliche Fehleinschätzung verwendet, zu Teil aber stärkere Varianz zwischen Trials
  + Limitations / open questions
    - Boundaries
    - Individual underestimation can drastically vary between different individuals (50-90%)
    - How is perceived size? (after manipulation)
* Transitional Environment
  + -> entstehen die Effekte aus dem transitional environment vlt durch die interaction time? (passive/aktive Bewegung durch Pforte
  + transitional environment in RW -> da aber wieder aufpassen mit Lernen aus der RW-Umgebung, da bekannte Umgebung ...)

# Summary and Outlook

* Zusammenfassung
  + Mean estimation of egocentric distances in VEs – 74% of modeled distances [Renner2013]
  + 50 – 90% [Renner2013]
* Fazit für einzelne Anwendungsbereiche
  + Während der Recherche kam für mich auch die Frage auf, ob das Thema Distanzwahrnehmung auch bei Flugsimulatoren bedeutend ist oder ob die Piloten einfach geübt genug sind, sich an den richtigen Tiefenreizen zu orientieren, sodass es nicht zu Fehleinschätzungen kommt. Da sind natürlich auch andere Entfernungen relevant als in den bisherigen Studien (bis 20m).
* Offene Fragen
  + Größere Entfernungen
  + Ist die Sichthöhe für jeden Teilnehmer angepasst worden?
  + Technical Factors:
    - Kaum Untersuchungen mit Displaywand und CAVE
    - HMD zeigt natürliche Umgebung, aufgenommen mit Kamera an HMD (oder weiter oben/unten)
    - Effekt von Zielobjekt-Wand-Entfernung
    - Einfluss der Entfernung zwischen Teilnehmer und Powerwall
    - Vergleich von unterschiedlicher VR-Hardware bisher kaum gemacht
    - 3D-Scan im Vergleich zu modellierter Umgebung -> Einfluss von Grafik-Qualität (conflicting results)
    - Einstellung IPD (conflicting results)
  + Human Factors:
    - Regelmäßiger Umgang mit VR
    - Gründe für Unterschiede zwischen den Teilnehmern (z.B. Alter, Stereopsis-Test)
    - Distanzen für jeden einzeln vergleichen. Besondere Effekte?
    - Einfluss von Präsenzgefühl
  + Virtual Environment:
    - Effekt von Entfernung des Zielobjekts zum Ende des Raums
    - Bekannte/unbekannte Umgebung
    - Indoor/outdoor (Natur, Straße -> andere Cues)
    - Andere Umgebung, z.B. Kathedrale. Vlt hat auch ein Bild von außen Einfluss auf die Distanzeinschätzung innerhalb der Kathedrale
    - Nutzung des 3D-Scanners um bekannte Umgebung der Studenten (Mensa, NHSG, Vorlesungssaal …) zu vergleichen
    - VE auf Powerwall ist Erweiterung des Labs
    - Transitional Environment
      * wie kann man die leicht verändern um Größen- und Entfernungseinschätzung zu manipulieren?
      * Welche Wirkung hat das nach dem Experiment?
      * Lässt sich das auch auf die Powerwall übertragen?
    - Self-Avatar in HMD (contradictory results)
  + Experimental Issues:
    - Ziele geradeaus auf dem Boden (2-20m)
      * Was ist mit Zielen auf Augenhöhe oder höher?
      * Was ist mit Zielen weiter rechts oder links?
    - Was ist mit größeren Entfernungen?
    - Welchen Einfluss hat die Wahl des Zielobjektes an sich?
    - Größere Teilnehmerzahlen
    - Eye height manipulation auch für Powerwall relevant/nutzbar?
    - Wirkung nach dem Experiment (carry-over effect)
  + Effects:
    - Welche VR-Anwendungen werden durch diesen Effekt überhaupt negativ beeinflusst?
* Empfehlungen
* Problematik der genutzten Entfernungen in Bezug auf verwendete Tiefenreize