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9 Using Virtual Reality in Experimental Psychology

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Abstract. The major aim of the present study is to emphasize the potential offered by Virtual Reality (VR) to develop new tools for research in experimental psychology. Despite several works have addressed cognitive, clinical and methodological issues concerning the application of this technology in psychological and neuro-psychological assessment and rehabilitation, there is a lack of discussion focusing on the role played by Virtual Reality and 3D computer graphics in experimental behaviour research. This chapter provides an introduction to the basic concepts and the historical background of experimental psychology along with a rationale for the application of Virtual Reality in this scientific discipline. In particular, the historical framework aims at emphasizing that the application of VR in experimental psychology represents the leading edge of the revolution that informatics has operated into the traditional psychology laboratory. We point out that the use of VR and Virtual Environments (VEs) as research tool might discover new methodological horizons for experimental psychology and that it has the potential to raise important questions concerning the nature of many psychological phenomena. In order to put the discussion on a concrete basis, we review the relevant literature regarding the application of VR to the main areas of psychological research, such as perception, memory, problem solving, mental imagery and attention. Finally, fundamental issues having important implications for the feasibility of a VR approach applied to psychological research are discussed.

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9.1 Introduction

9.1.1 The history of scientific psychology and of its experimental instruments

The emergence of scientific psychology in the period 1855–1914 constituted an important advance in the history of human understanding. For centuries issues such as the characteristics of human and animal mind, the relationship between mind and body, the relative roles of cognition, and the nature of mental healing were the subject of philosophical speculation and debate. The adoption of the experimental method by psychological research can be considered as the point of transition of the psychological investigation, which moved from a speculative approach of the great philosophers to the empirical approach of the modern scientific method. The method of this new science was to be experimental. As Wundt [1] phrased it, "Psychological introspection goes hand in hand with the methods of experimental physiology, and the application of the latter to the former has given rise to the psychophysical methods as a separate branch of experimental research. If one wishes to place major emphasis on methodological characteristics, our science might be called *experimental psychology* in distinction from the usual science of mind based purely on introspection".

Physiology made an important contribution to the emergence of scientific psychology through its development of experimental apparatus. In order to study physiological processes with the care and precision required for the generation of reliable findings, experimental physiologists developed a wide array of instrumentation. The function of these instruments was to control variation in stimulus presentation or to register and measure response. Among the instruments designed for the control of variation in stimulus presentation, for example, were the color mixer (for varying wavelength composition and/or brightness of a visual stimulus), the aesthesiometer (for varying tactile stimuli), the accoumeter (for varying amplitude of sound), and the tonometer (for varying frequency of sound). Apparatus designed to register and measure response included the kymograph (which allowed analogue registration of a continuous response), the cardiograph (for heart rate), the plethysmograph (for pulse), the ergograph (for effort expended and fatigue), and the chronoscope [2].

At the end of the 19th century, as psychologists began to set up laboratories for experimental research, it was natural for them to look to physiology for basic apparatus; and items of the sort listed above became standard fixtures in these laboratories. In addition, psychologists began to develop specialized apparatus of their own. Often these instruments were designed for research on higher or more complex mental processes.

Examples might include Georg Elias Myller's *memory apparatus*, Felix Krueger's *larynx sound recorder*, Karl Marbe's apparatus for the melody of speech, and Emil Kraepelin's writing apparatus.

The informatics revolution of the second half of the 20th century increased the diffusion of the use of the computer in psychology research. Although initially experimental psychologists used the computer mainly for gathering and processing experimental data, later it became an important support of all phases of the experimental procedure, from task presentation to on-line storage and recording of subject's responses.

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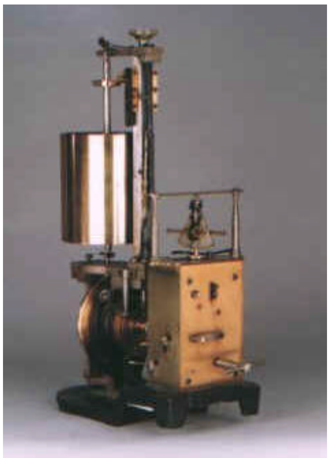

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Figure 9.1 Early psychology instruments: a) Hipp chronoscope; b) Aesthesiometric Compasses; c) Vertical Kymograph; d) Tonometer (*courtesy of the University of Toronto Brass Instrument Collection*).

Legrenzi [3] indicated four main factors by which the beginning of the informatics era might have characterized the revolution of the traditional psychology laboratory:

1. *Dehumanisation*. One of the most important methodological innovations introduced by Wundt was the division of roles between the observer and the subject. The subject, according to Wundt, was merely the source of the data while the observer was charged with manipulating the stimuli and measuring/interpreting subject's responses. In this way, the result of the investigation became the product of a social interaction following a system of rules defined by a scientific procedure. The introduction of the computer restricted even more the role of the subjects, by constraining them to give their response in very bound tasks.

2. *Simulation*. The possibility of simulating the investigated phenomena by using the computers offered a new tool for experimental research. The use of the computer-simulation of natural phenomena assumed a fundamental role not only in psychology, but also in several other scientific disciplines, like physics, chemistry, biology and meteorology.

3. *Creation of artificial phenomena*. The development of new methods for the creation of artificial phenomena offered the researchers the opportunity of using artificial systems (i.e. neural networks) to emulate the response of a human being. This determined a radical transformation of the concept of “division of roles” as was intended by Wundt, since the subject was beginning to be replaced by artificial systems. However, this replacement was - and currently is - limited to a restricted range of phenomena, because due to their complexity most part of psychological effects cannot be simulated or re-created by using artificial systems.

As Legrenzi points out, the emergence and growth of information technology transformed the traditional psychological laboratory. The laboratory was not any longer understood as an environment where the subject’s response could be observed under controlled conditions, but as an environment where a set of natural phenomena, classified as “cognitive events”, could be created and/or simulated. Moreover, the development of new computer software and hardware for the controlled presentation of stimuli and the accurate recording and measurement of reactions strengthened the belief that experimentation could yield progress in the description and explanation of psychological phenomena. Finally, it should be emphasized that the impact of the computer on psychology was not only circumscribed to the laboratory research. In fact the adoption of the computer as a metaphoric/symbolic model of the human mind [4] determined the beginning of a new scientific movement, the *cognitive science*, which represents the leading theoretical model of present experimental psychology.

9.1.2 A brief historical outline of Virtual Reality technology

The technology of Virtual Reality is not as recent as one might suppose. The first VR system appeared early in the 1962, as Morton Heilig presented a first prototype of multi-sensorial simulator called *Sensorama*. The prototype was a simulator of a real experience (a motorcycle ride through New York) complete with fan-generated wind, the smells and the noise of the metropolis. The *Sensorama* had all main features of a modern Virtual Reality system with one exception: there was no possibility of interaction by the user, because the route was fixed and pre-recorded. Few years later Ivan Sutherland, one of the pioneers of computer graphics (Sutherland's first computer-aided design program, called *Sketchpad*, opened the way for designers to use computers to create blueprints of automobiles, cities, and industrial products), described and realized the first head-mounted display, a visual device which can display an image in front of the user's eyes, no matter where the user may be looking. Key innovative features of Sutherland’s HMD were the implementation of stereoscopic vision, the fact that the visual images were computer-generated (and not produced by a video cam) and the adaptation of the user’s view according to the head’s movements (visual feedback) [5]. He wrote also about force-feedback-devices.

The introduction of flight simulators was one of the most important precursors to Virtual Reality. By the 1970s, computer-generated graphics replaced videos and models that had been used since the Second World War. Fight simulations were operating in real time, though the graphics was primitive. In 1979, the military started to experiment fight simulation systems that used head-mounted displays. These innovations were driven by the greater dangers associated with training on and flying the jet fighters that were being built in the 1970s. In the mid-1980’s, a limited three-dimensional virtual workspace in which the user interactively manipulated three-dimensional graphical objects spatially corresponding to hand position was developed. In 1984, NASA started the VIVED project (Virtual Visual Environment Display) and later the VIEW project (Virtual Interactive

Environment Workstation). The goal of both projects was to develop a multipurpose, multimode operator interface to facilitate natural interaction with complex operational tasks and to augment operator awareness of large-scale autonomous integrated systems [6]. Virtual Reality was introduced to the general public first in 1989, at two trade shows organized by two companies (AutoDesk and VPL Research) involved with NASA projects.

The term "Virtual Reality" was originated at that time by J. Lanier, defining it as "a computer generated, interactive, three-dimensional environment in which a person is immersed". Through the 1990s, faster computers provided the key to interactivity; scientists developed advanced visualization software programs and many research centres started at working on VR applications in education, medicine, industry, military training and entertainment. At present, the number of human activities that benefit of VR technology is constantly increasing and further positive expectations are made thanks to the growing diffusion of wireless devices and wearable computing, which represent the new frontier of the research concerning VR interfaces.

9.2 The application of VR technology in Experimental Psychology: the rationale

While many Virtual Reality applications have emerged in several human activities, only recently Virtual Reality technology has been recognized as a useful medium for the study, assessment, and rehabilitation of cognitive processes and functional skills [7]. The opportunity offered by Virtual Reality technology to create interactive three-dimensional stimulus environments, within which all behavioural respondings can be recorded, offers experimental psychologists options that are not available using traditional techniques.

The main benefits offered by the application of VR technology to experimental psychology can be summarized as follows:

1. *Ecological validity.* A clear advantage of a Virtual Reality system is the capacity to record and measure naturalistic behaviour within a simulated functional scenario. This asset offers the potential to collect reliable data which might be otherwise lost to methods employing behavioural ratings from trained observers of behaviour in "real" world settings [8]. Virtual Reality allows researchers to carry out dynamic testing and training in an ecologically valid or "real-world" manner, while still maintaining strict control over all aspects of the experimental situation.

2. *Flexibility.* Virtual environments are highly flexible and programmable. They enable researchers to present a wide variety of controlled stimuli and to measure and monitor a wide variety of responses made by the subject [9]. Furthermore, both the synthetic environment itself and the manner in which this environment is modified by the user's responses can be tailored to the needs of each experimental setting.

3. *Sensorial Feedback*. Our sense of physical reality is a construction derived from the symbolic, geometric, and dynamic information directly presented to our senses. The output channels of a Virtual Reality application, thus, should correspond to our senses: vision, touch and force perception, hearing, smell, and taste. At the present time a good choice of commercial products exists for visual, tracking and user input interfaces. Auditory and haptic interface technologies are becoming ready for use in practical applications, while olfactory interface is the least mature of all the feedback technologies. Despite of the immaturity of some of these input devices, the ones available at present can represent a powerful tool for behavioural research, in particular for studies requiring the simulation of complex sensorial effects otherwise difficult – if

not impossible - to reproduce with traditional methods (i.e., the translation of one sense into different senses).

4. *Performance Recording.* VR and related technologies allow the complete performance recording. This can avoid the loss of important experimental data, which is a common drawback, for example, of traditional pen-pencil based observational methods.

The next section will present a summary of the VE literature targeting cognitive/functional processes in experimental psychology.

9.3 Empirical work in behaviour research involving Virtual Reality technology

Having set out the rationale for the application of Virtual Reality in experimental psychology, we will now try to make these ideas more concrete. Rather than attempt to a global review, we shall concentrate on a small number of influential studies to draw out some general issues pertinent to our aim of assessing the pros and cons of this new tool for behaviour research.

9.3.1 Perception

The study of sensation and perception involves not only the anatomy and physiology of the sensory system, but also behavioural measures. Psychophysical data obtained from tasks in which observers are asked to detect, discriminate, rate or recognize stimuli provide information about how the properties of the sensory system relate to what is perceived.

Behavioural measures also provide considerable information about the function of higher-level brain processes for which current knowledge of the physiological bases is rudimentary. The sensory information must be interpreted by these higher-level processes, which include mental representations, decision-making, and inference. Thus, perceptual experiments provide evidence about how the sensory input is organized into a coherent percept. Methods for investigating sensation and perception include *anatomical-physiological methods* and *psychophysical methods*. The former are represented by a wide variety of specific techniques for analysing and mapping out the pathways associated with sensation and perception and include both neuropsychological and psychophysiological techniques, which are used to investigate issues concerning information processing.

Psychophysical methods aim at obtaining some estimate of sensitivity to detect either the presence of some stimulation or differences between stimuli. In this framework, VR should be interpreted as a useful tool, which can *support* and *improve* both anatomical-physiological and psychophysical methods. Taken for granted that the simulation of reality in its infinite complexity is far beyond the possibility of present Virtual Reality systems, the major advantage offered by the use of VR in perception research is represented by the possibility of investigating the perceptual mechanisms using specific virtual stimuli tailored to the needs of each experimental task.

It is interesting to point out that Virtual Reality technology was developed by implementing many perceptual laws discovered by experimental psychologists during the last century. To some extent, one might say that 3D computer graphics has recapitulated the development of psychological knowledge in this area. Now experimental psychology has the opportunity to use this technology to reach a deeper understanding of some perceptual phenomena, which otherwise might not be investigated at all. This not only demonstrates that findings in one scientific discipline are often easily applied to others, but also that the relationship between the questions scientists ask and the apparatus that they have available for research is bi-directional. Theoretically derived questions may motivate the search for adequate apparatus; and apparatus, once developed, not only permits but in some cases also drives the search for additional questions. Actually, beyond the scientific questions raised by the possibilities offered by VR technology regarding known perceptual and cognitive phenomena, the experience of being immersed in a synthetic environment itself might represent a new theoretical construct (the sense of *presence*) that is worth being investigated.

The range of perceptual phenomena investigated using Virtual Reality is quite heterogeneous, demonstrating that VR has the potential to be applied to several fields of perceptual research. Therefore, the best approach for a review would be to classify the studies according to the perceptual processes targeted by VR applications. The review is not meant to be complete, rather to illustrate examples of relevant studies where the added value of VR technology to traditional anatomical-physiological and psychophysical methods can be emphasized.

9.3.1.1 Visual perception

Seeing is the process of decoding the image information conveyed by patterns of light. 3D computer graphics simulates the process of encrypting scene information into the image.

By presenting subjects with computer-generated 3D stimuli, we can gain powerful insights into the constraints used by the visual system to decode image information and assess the roles of specific visual cues in determining the visual percept. Conversely, knowledge of the minimal conditions for the perception of visual environmental properties can be used in the design of more effective optical displays. This bi-directional relationship between perception research and advance in VR technology is well represented, for instance, by studies which examined the effectiveness of using perceptual criteria to select the amount of detail that is displayed in an immersive Virtual Reality (VR) system. Based upon this determination, Reddy et al. [10] developed a principled, perceptually oriented framework to automatically select the appropriate level of detail (LOD) for each object in a virtual scene, taking into consideration the limitations of the human visual system. They applied knowledge and theories from the domain of visual perception to the field of VR thus optimising the visual information presented to the user based upon solid metrics of human vision. The rationale of this approach was that, if one could describe one object in terms of its spatial frequencies, this would enable to select the lowest LOD available without the user being able to perceive any visual change.

Another example of the bi-directional relationship between perception research and advance in VR technology is represented by research on distance perception. Perceived distance judgments have been previously studied in both naturalistic and laboratory settings. The initial investigations of distance estimation in VEs have been carried out to determine how accurately people perform distance estimation tasks under tightly controlled conditions and to assess how selected distance cues influence their estimates. By assessing the contribution of the various distance cues to distance perception, researcher can not only gain insights to the processes underlying spatial perception, but they can also investigate factors that may have potential to improve the visual fidelity of a VE [11]. Surdick et al. [12] compared the effectiveness and accuracy of multiple depth cues across viewing distances to examine which cues should be implemented in a visual display in order to minimize costs while maximizing the effectiveness of depth information. For example, the binocular displays required for stereopsis (a depth cue based on stimulation of disparate locations on the retinae) are more costly and complex than biocular displays. If stereopsis provides effective and accurate depth information for task performance (e.g., in performing surgery), then perhaps it should be included in the display. However, if other cues (e.g. perspective depth cues) are just as effective and accurate but less costly, then perhaps these perspective depth cues should be incorporated into the display instead. Results of this study showed that the use of perspective cues in simulated displays may be more important than other depth cues tested because these cues are the most effective and accurate, can be easily perceived by all subjects, and can be readily incorporated into simpler displays (e.g., biocular HMDs).

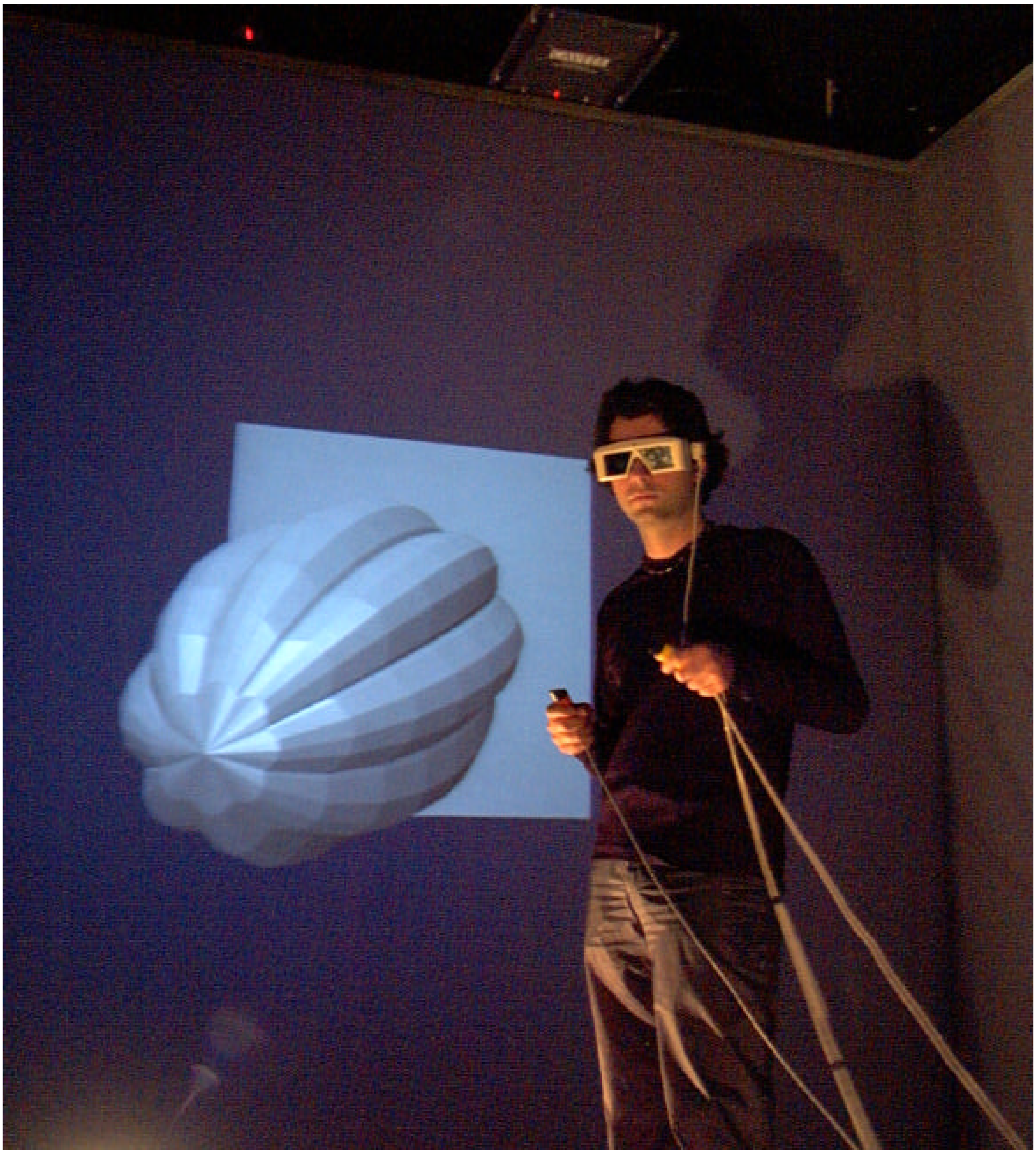

Figure 9.2 An experiment on visual perception performed in a full-immersive Virtual Reality system (*courtesy of Fraunhofer IAO, Stuttgart, Germany*).

In another study, Gaggioli and Breining [13] investigated how stereo vision and different monocular coding techniques (Wireframe, Flat-Shading and Gouraud Shading) affect the ability to estimate the depth of a 3D computer-generated object displayed on the front wall of a four-walls CAVE (a projection-based VR system that surrounds the viewer with 4 screens) capable of both stereoscopic and monoscopic modes. Results showed a significant positive effect of binocular disparity on perceptual performance, but when concave 3D-shapes were used as stimuli. Furthermore, perceptual estimates were found more accurate and easier when the 3D object's surface was rendered with less realistic monocular coding techniques, like Wireframe and Flat-Shading.

Servos et al. [14] assessed stereo-motion thresholds with high-resolution computer monitor. Stereo-motion thresholds for a rectangle oscillating in depth were determined with the use of a dual randomly interleaved staircase design. By assessing the thresholds for a rectangle that was defined either by lateral motion or by changing size in a group of experienced observers, the authors were able to show that any potential residual translational motion present in the display would not have influenced the stereo-motion thresholds. These findings suggest that this computer-graphics-based technique may be a reasonable alternative to optics-based methods of assessing stereo-motion thresholds.

Harris et al. [15] used a VR display to assess the role of visual and vestibular cues in determining the perceived distance of passive, linear self-motion. Subjects were given cues to constant-acceleration motion: either optic flow presented in a Virtual Reality display, physical motion in the dark or combinations of visual and physical motions. Subjects indicated when they perceived they had traversed a distance that had been previously given them either visually or physically. Results showed a dominance of the physical cues in determining the perceived distance of self-motion in terms of capture by non-visual cues.

The authors related these findings to emerging studies showing the importance of vestibular input to neural mechanisms that process self motion.

Distler et al. [16] investigated the effect of velocity constancy in a Virtual Reality environment. In this study the authors used a virtual environment (VE) to investigate how cues to speed judgments are integrated. The results of this research suggest that both low-level cues to spatio-temporal structure and depth, and high-level cues, such as object familiarity, are integrated by the brain during velocity estimation in real-world viewing.

Shikata et al. [17] used a 3D computer graphics display to identify a group of neurones in the posterior parietal cortex of the monkey that responded preferentially to a flat stimulus in a particular 3D orientation. By using this methodology the authors were able to provide evidence that SOS neurones extract surface orientation signals from the binocular disparity signals and play an important role in the perception of 3D shape and the visual guidance of hand movement.

9.3.1.2 Visuospatial navigation

Research on human spatial cognition aims at investigating the cognitive mechanisms that are triggered in environmental perception and in the representation of spatial information in the environment. The methodology used in this research is usually based on static measures of spatial behaviour, either in real settings or in laboratory simulations (such as film or slide projections). The limits of this approach are that it is difficult to control all environmental parameters in real settings and, on the other side, laboratory simulations are often unrealistic [18]. Virtual Reality has the potential to override such problems. In fact, it allows to make continuous measurements during navigation and to design three-dimensional environments of varying complexity and realism levels. Moreover, real-time interactivity (and head-tracking) in three-dimensional spaces can give the feeling of actual immersion.

Finally, the use of virtual environments can be combined with functional brain imaging techniques, which are useful to identify the neural basis of navigation [19]. For example, Gron G. et al. used functional MRI (*Magnetic Resonance Imaging*) to observe brain activation in male and female subjects as they searched for the way out of a complex, three-dimensional, virtual-reality maze [20]. Results of MRI showed that navigation activated the medial occipital gyro, lateral and medial parietal regions, posterior cingulated and parahippocampal gyri as well as the right hippocampus proper. Gender-specific group analysis revealed distinct activation of the left hippocampus in males, whereas females consistently recruited right parietal and right prefrontal cortex. According to the authors, these findings demonstrate a neural substrate of well-established human gender differences in spatial-cognition performance.

Sandstrom et al. [21] used a computer-generated virtual environment to study sex differences in human spatial navigation. Adult male and female participants navigated through a virtual water maze where both landmarks and room geometry were available as distal cues. Manipulation of environmental characteristics revealed that females rely predominantly on landmark information, while males more readily use both landmark and geometric information. The authors discussed these results as a possible link between recent human research reporting hippocampus activation in spatial tasks and animal work showing sex differences in both spatial ability and hippocampus development.

A fundamental property of the human brain is the ability to make predictions of future sensory and motor events. Grasso et al. [22] simulated navigation along a multi-legged virtual corridor in order to understand whether a time-related or space-related signal triggers anticipatory head orienting movements. Results showed that anticipatory orienting movements are triggered (in standing subjects) by reaching specific locations rather than by the time to the approaching corridor's bend. Similar to what happens in car driving, specific spatial features of the route rather than time to collision seem to drive steering.

9.3.1.3 Sensorimotor transformation

Carrozzo et al. [23] investigated viewer-centred and body-centred frames of reference in direct visuomotor transformations. A Virtual Reality system was used to present visual targets in different three-dimensional (3D) locations in two different tasks, one with visual feedback of the hand and arm position (Seen Hand) and the other without such feedback (Unseen Hand). The findings from these and previous experiments support the hypothesis of a two-stage process, with a gradual transformation from viewer-centred to body-centred and arm-centred coordinates. Retinal, extra-retinal and arm-related signals appear to be progressively combined in superior and inferior parietal areas, giving rise to egocentric representations of the end-point position of reaching.

In a research published in *Nature Neuroscience*, Rushton and Wann [24] used a Virtual Reality task to verify a computational model for timing hand closure to catch a ball. The model is sensitive to the relative effectiveness of size and disparity and implicitly switches its response to the cue that specifies the earliest arrival and away from a cue that is lost or below threshold. The authors demonstrate the model's robustness by predicting the response of participants to some very unusual ball trajectories.

Blakemore et al. [25] have examined the role of sensorimotor context estimation in predicting the consequences of our own actions. They postulated that an efference copy of the descending motor command, in conjunction with an internal model of both the motor system and environment, enables us to predict the consequences of our own actions. In order to test this hypothesis, the authors used two robots to simulate virtual objects held in one hand and acted on by the other. Precise predictive grip force modulation of the restraining hand was highly dependent on the sensory feedback to the hand producing the load. The results show that predictive modulation requires not only that the movement is self-generated, but also that the efference copy and sensory feedback are consistent with a specific context; in this case, the manipulation of a single object.

VR has been also successfully applied to the study of the regulation of human locomotion. Buekers et al. [26] investigated how human locomotion is regulated under externally paced temporal constraints. In this study, a virtual hallway in which a pair of doors was presented that continuously opened and closed at a rate of 1 Hz was projected on a screen placed in front of a treadmill. Subjects were attached to a locometer and instructed to regulate walking pace such that the doors were passed correctly. Performance outcome, movement kinematics (stride duration, stride length and synchronization of stride and door cycles) and flow patterns (change in visual angle of door aperture) were used to examine the data. The findings of this study showed that regulations of locomotion under externally paced temporal constraints are postponed until the final stage of the approach during which adaptations are made according to the requirements of the current situation.

9.3.1.4 Haptic perception

Haptic displays are devices for presenting tactile and force sensations. These displays are being developed in several laboratories, but are not yet widely used elsewhere. Most of the haptic displays available are electro-mechanical devices that deliver force feedback to the hand or arm within limited ranges of movements. For both these reasons, few researches used VR to investigate haptic perception.

Using a visuo-haptic Virtual Reality environment, Atkins et al. [27] tested the hypothesis that observers can use haptic percepts as a standard against which the relative reliabilities of visual cues can be judged, and that these reliabilities determine how observers combine depth information provided by these cues. The results suggest that observers can involuntarily compare visual and haptic percepts in order to evaluate the relative reliabilities of visual cues, and that these reliabilities determine how cues are combined during three-dimensional visual perception.

9.3.2 Attention

Traditional methods for the study of attention usually include pencil and paper techniques, motor reaction time tasks in response to various signaling stimuli and flat-screen computer programs. As Rizzo [28] suggests, within a VR setting a person could be systematically tested and trained on attentional tasks that incorporate settings and response requirements that could simulate real-world functional environments beyond what currently exists.

Virtual Reality, in particular, is well suited to investigate *selective attention* (the ability to maintain behavioural or cognitive set in the face of distracting or competing stimuli) since this cognitive ability is best studied under conditions similar to the three-dimensional, real-world action in which humans typically engage.

Maringelli et al. [29] investigated the shift of visuo-spatial attention in a virtual three-dimensional space. A Virtual Reality set-up was used to study attentional orienting within a three-dimensional visual world. Near and far stimuli were used. Half of the subjects were provided with a virtual representation of their body, whereas half were not. Results showed a different distribution of attentional resources in the two conditions, suggesting a dissociation between attentional systems controlling the proximal and the distal visual space. In particular, the authors found that attention was focused close to the subject's body when a virtual representation of it was present, whereas attention was focused away from the body when a virtual representation of the body was not present.

Lyons J. et al. [30] performed three experiments to assess the predictions of an action-centred model of selective attention. Participants were required to direct action to intended targets located within a computer-generated virtual environment. Using this methodology, the authors found evidence that human selective attention is predominant influenced by the degree to which perception and action space are aligned.

9.3.3 Memory

The main applications of Virtual Reality technology into the field of memory research are concerned with topographical memory and the representation of spatial knowledge.

Environmental psychology models propose that knowledge of large-scale space is stored as distinct landmark (place appearance) and survey (place position) information. Studies of brain-damaged patients suffering from "topographical disorientation" tentatively support this proposal. In order to determine if the components of psychologically derived models of environmental representation are realized as distinct functional, neuroanatomical regions, Aguirre and Desposito [31] performed a functional magnetic resonance imaging (fMRI) study of environmental knowledge. During scanning, subjects made judgments regarding the appearance and position of familiar locations within a Virtual Reality environment. A direct comparison of the survey position and landmark appearance conditions revealed a dorsal/ventral dissociation in three of four subjects. According to the authors, this experiment confirms that environmental knowledge is not represented by a unitary system but is instead functionally distributed across the neocortex.

Virtual Reality was also used to test cognitive models of environmental learning (for a survey, see Wilson [32]). These models ascribe a key role to salient landmarks in representing large-scale space. In order to further investigate this hypothesis, Maguire et al. [33] examined the neural substrates of the topographical memory acquisition process when environmental landmarks were specifically identifiable. Using positron emission tomography (PET), they measured regional cerebral blood flow changes while normal subjects explored and learned in a Virtual Reality environment. One experiment involved an environment containing salient objects and textures that could be used to discriminate different rooms. Another experiment involved a plain empty environment in which rooms were distinguishable only by their shape. Learning in both cases activated a network of bilateral occipital, medial parietal, and occipitotemporal regions. The presence of salient objects and textures in an environment additionally resulted in increased activity in the right parahippocampal gyrus. This region was not activated during the exploration of the empty environment. According to the authors, these findings suggest that encoding of salient objects into a representation of large-scale space is a critical factor in determining parahippocampal involvement in topographical memory formation in humans.

In another experiment, Astur et al. [34] used a computerized version of the Morris water task to examine whether sex differences exist in this domain of topographical learning and memory. This task represents the standard for measuring place learning ability in non-human mammalian species and requires subjects to use the spatial arrangement of cues outside of a circular pool to swim to a hidden goal platform located in a fixed location.

Across three separate experiments, varying in attempts to maximize spatial performance, the authors consistently found males navigate to the hidden platform better than females across a variety of measures. The authors emphasize that these results show a robust sex difference in virtual place learning and demonstrate the effectiveness and utility of the virtual Morris water task for humans.

Gender differences in acquisition of navigational knowledge were found also by Cutmore et al. [35]. The authors performed five experiments to examine the influence of gender, passive/active navigation, cognitive style, hemispheric activation measured by electroencephalography and display information on the acquisition route and survey knowledge using a virtual environment. The results showed that males acquired route knowledge from landmarks faster than females and that proficiency in visual-spatial cognition is associated with better performance in situations where survey knowledge must be used. Furthermore, EEG showed that the right cerebral hemisphere appears to be more activated than the left during navigational learning in a VE. According to the authors, these results have a number of implications in the use of VEs for training purposes and may assist in linking processes involved in navigation to a more general framework of visual-spatial processing and mental imagery.

Richardson et al. [36] investigated spatial knowledge acquisition from maps and from navigation in real and virtual environments. In this experiment, participants first learned the layout of a simple desktop VE and then were tested in that environment. Then, participants learned two floors of a complex building in one of three learning conditions: from a map, from direct experience, or by traversing through a virtual rendition of the building. The authors found that VE learners showed the poorest learning of the complex environment overall. However, all the conditions showed similar levels of performance in learning the layout of landmarks on a single floor. Learning the initial simple VE was highly predictive of learning a real environment, suggesting that similar cognitive mechanisms are involved in the two learning situations.

The specificity of spatial memory performance in a virtual environment was studied by Brooks et al. [37]. Two experiments investigated differences between active and passive participation in a computer-generated virtual environment in terms of spatial memory, object memory, and object location memory. The authors found that active participants, who controlled their movements in the virtual environment using a joystick, recalled the spatial layout of the virtual environment better than passive participants, who merely watched the active participants' progress. Conversely, there were neither significant differences between the active and passive participants' recall and recognition of the virtual objects, nor in their recall of the correct locations of objects in the virtual environment.

According to the authors, these findings emphasize the specificity of memory enhancement in virtual environments.

Gamberini [38] performed two experiments to analyse the effects of immersive and nonimmersive (desktop) VR displays for a three-dimensional environment on memory performance. The tasks consisted in: a) the recognition of the objects perceptual characteristics after exposure to the virtual environment and 2) the recollection of the objects locations in the virtual environment. Quite surprisingly, results showed that subjects performed better in the nonimmersive (desktop) condition for both objects recognition and objects location recollection memory tasks. The author attributed the lack of a positive effect of the immersive display to the inadequacy of the surfing-command interface available for the subjects in such condition, thus emphasizing the importance of the usability issues concerned with the input instruments in navigating in electronic environments.

9.3.4 Cognitive performance

As means of representing and interacting with information, Virtual Reality is at the forefront of technological development. Despite claims that much can be gained from interacting with virtual environments and graphical animation, however, researchers did not consistently demonstrate benefits for cognitive performance. For example, it is not yet clear why particular graphical representations which change response to user interaction should be more effective at facilitating problem solving than static graphical representations, or why three-dimensional representations are better than two-dimensional ones. Scaife and Rogers [39] have developed an analytic framework from which these and other questions regarding graphical representations might be explained. In this framework three central characteristics are emphasized:

- *Computational offloading*. This refers to the extent to which differential external representations (referred both to linguistic and graphical forms) reduce the amount of cognitive effort required to solve informationally equivalent problems.

- *Re-Representation*. This refers to how different external representations, that have the same abstract structure, make problem solving easier or more difficult. The authors report as an example how Zhang and Norman [40] describe carrying out the same multiplication task using roman or Arabic numerals. Both represent the same formal structure, but the former is much harder for people, used to working with the decimal system, to manipulate to reach the solution (e.g. LXVII $\times$ X is much more difficult to solve than 68×10).

- *Graphical constraining*. This final feature of the framework refers to the way graphical elements in a graphical representation are able to constrain the kinds of inferences that can be made about the underlying represented world. The authors' central idea about this characteristic is that the relations between graphical elements in a graphical representation are able to map onto the relations between the features of a problem space in such a way that they restrict (or enforce) the kinds of interpretations that can be made. The closer the coupling between the elements in the visual display and the represented world, the more tractable the inferencing. Scaife and Rogers point out that computational offloading and re-representation are not overlapping, but complementary. In fact, the former highlights the cognitive benefits of graphical representations while the latter relates to their structural properties and graphical constraining to possible processing mechanisms.

By using this framework, Scaife and Rogers identify some problems that could drive further empirical research concerning human cognitive performance in Virtual Reality.

First, the authors emphasize that the value of Virtual Reality should not be assumed to come about through a structural and spatial equivalence between the Virtual Reality simulation and the real world. In fact, preliminary findings from studies investigating transfer of training in VR systems show that performance characteristics of a task learnt in a VR context are of limited utility when carrying out the same task in the real world. So, instead of considering VR immersion in terms of the value gained from attaining higher levels of perceptual fidelity with the real world, the authors consider more useful to determine what aspects of the represented world need to be included in the virtual environment, what aspects should be omitted and what additional information needs to be represented that is not visible in the real world but enhance task's performance. From a cognitive perspective, this approach enables researchers to assess the benefits of VR in terms of the processing mechanisms that operate at different levels of abstraction of information.

Another way in which the value of VR can be characterized is in terms of "steering" the interaction, in that VR simulations provide more opportunities to visualize and manipulate the behaviour of abstract data structures or processes which are not otherwise visible (for example, the simulation of virtual smoke stream for fluid dynamics, which enables a scientist to manipulate the fluid by using finger tips). The assumption here is that better mental models of the abstract processes will develop through making these kinds of processes more concrete and that on-line problem solving will be facilitated [41]. Scaife and Rogers, however, emphasize that this approach of defining the value of VR does not fully explain how experts, who are supposed to be highly familiar with abstract representations and have to interact with them in their work, are able to transfer between these forms of representation and the concretised visual representation of the same problem space in the Virtual Reality simulation. For the authors, therefore, the value of being able to "steer" a physical simulation should be analysed in relation to how it integrates with ways of interacting with other existing forms of external representations in professional practice.

9.3.5 Mental imagery

Mental imagery is the cognitive process that resembles perceptual experience, but which occurs in the absence of the appropriate stimuli for the relevant perception [42]. Mental imagery is centrally involved in visuo-spatial reasoning and inventive or creative thought. Indeed, it has usually been regarded as crucial for *all* thought processes, although, during the 20th century in particular, this has been called into question. Cognitive psychologists have hypothesized two main models that describe how images are processed and represented in human memory: these are known as the *analogue* model and the *propositional* model [43].

The analogue model asserts that visual information is stored as images, which correspond closely with actual visual images as received by the retina. This correspondence is maintained during mental transformation as if the real object was itself being transformed.

According to the propositional model, images are stored as set of propositions, which are memory representations structured according to specified rules of formation and must be either true or false with respect to the image. To explore mental images more objectively, researchers give subjects tasks that seem to require the use of mental images.

As a critical part of the task is varied, some characteristics of mental images can be deduced. Roger Shepard and his colleagues designed one of the most often used tasks. In the original task subjects were shown two novel visual stimuli projected on a tachistoscope and were asked to determine whether the stimuli had the same shape or different shapes.

The shapes (random block shapes) were rotated either in the plane or in depth. Subjects reported that they mentally rotated an image in their head until the two stimuli were oriented the same way, and then made their judgment. When subjects were asked to make their response as quickly as possible, the reaction time increased with the angle of rotation between the shapes. This suggests that it takes time to mentally rotate an image, and implies that mental images are much like real images (thus providing evidence for the analogue model) [44]. With the advance of 3D computer graphics, it became possible to adapt the mental rotation paradigm to study the effect of several shape and realism cues in order to achieve a better comprehension about how visual images are processed and stored in human memory. Barfield and Salvendy [45] investigated the effects of object complexity (three levels, all shown as wireframe images with hidden edges) on mental rotation rates. Reaction times indicated that mental rotation rates were significantly longer for wireframe images than for standard Shepard-Metzler figures and that the reaction time functions were non-linear and related to image and task complexity. The authors used these results to provide preliminary evidence for a third model of mental imagery, called the *hybrid* model for mental rotation, which contains features of both the analogue and propositional positions. In a later study Barfield, Sanford and Foley performed one experiment to investigate the effect of computer-generated realism cues (hidden surfaces removed, multiple light sources, surface shading) on the speed and accuracy with which subjects performed the mental rotation task [46]. Results indicated that mean reaction times were faster for shaded images than for wire frame images (with hidden surfaces removed) and evidenced significant effect for object complexity. According to the authors, these results are consistent with the hybrid model described above.

Gallimore [47] investigated differences in subjects' ability to discriminate between the shape of two 3d objects (a task similar to the classic mental rotation paradigm except that subjects were provided with the ability to rotate one of the objects using a two-dimensional joystick) for various levels of monocular coding techniques and stereopsis. Results indicated that interposition enhanced performance and that stereopsis did not help subjects in performing the visualization task used in this experiment. Brown [48] used a modified version of the standard rotation paradigm in order to consider long-term memory characteristics. In the modified study, subjects were forced to compare a visible stimulus to an object existing in memory. The manipulated variables were interposition and stereoscopic vision. Results showed a positive effect of interposition on performance and a significant, albeit limited, positive effect of stereopsis. Actually, the effect of stereopsis was only measurable for trials with rotated stimuli lacking in clear cues to object structure.

The authors interpreted this result by supposing that stereopsis represents a useful visual cue when other cues to stimulus structure are insufficient and/or ambiguous.

9.4 Conclusion

Virtual Reality is becoming a commonly used research tool in experimental psychology, and the studies of those researchers who apply this technology are acknowledged and even encouraged by the scientific community. In addition, this trend is reinforced by reduced computer size, lower costs and significant increase in computing power, which are likely to make advanced computer systems available in many psychology laboratories. However, for this technology to be successfully applied to the available behaviour research methodologies, efforts must be made both by behaviour and computer scientists in order to override some methodological and technical problems.

A fundamental issue having important implications on the feasibility of a VR approach applied to psychological research concerns the concept of generalization of measurement. In fact, it is not fully understood whether, and to which extent, results concerning a hypothesis tested in a virtual environment setting can be extended to day-to-day, real-world life [49]. Experiences offered in Virtual Reality are restricted to what perceptual cues we can reproduce and are much more limited than the sensorial-rich experiences available to an individual going about daily routine. This limitation, therefore, should be taken in account when attempting to generalize results obtained using a Virtual Reality simulation to explain the behaviour observable in a natural setting.

A second problem concerns the limitations of the current sensorial output devices. In fact, although devices with 3D sound and tactile feedback are available, virtual environments are mainly designed around the visual modality and do not account for interactions among the sensorimotor systems. This constrain, thus, reduces drastically the range of experimental situations where VR could be applied.

Another technical problem is represented by the lack of reference standards. In fact, almost all the VR applications in behaviour research are “one-off” creations tied to their development hardware and software. This makes it difficult to use them in context others than those in which they were developed [7].

Finally, the issues related to the user interface should be not disregarded. The essence of Virtual Reality is the ability to interact with a three-dimensional computer-generated environment. If this technology has to become an effective research tool in experimental psychology, the goal is to build applications that allow a person to interact with the electronic environment in a naturalistic fashion. Furthermore, the development of more naturalistic interfaces could have positive implications for the concerns on generalization discussed above.

In conclusion, although Virtual Reality technology represents a promising tool in areas of experimental research such as those described above, a need is identified for more fundamental systematic research about methodological, technical and human factors issues so as to improve understanding of the potential offered by this innovative technology to scientific psychology.

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