Virtual environments and the cyberadaptaion syndrome

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The development of computer generated virtual environments (VEs) has made it possible to create virtual worlds in which an individual can feel present—that is, as if he or she were actually in the virtual environment (Sheridan, 1992). The user can move about in some VEs and can manipulate objects, either virtual objects or real objects, telerobotically. Some VE systems involve head-mounted displays (HMDs), others video monitors or projection screens. The sense of presence or immersion in a VE is enhanced by a greater degree of fidelity of a depicted environment to a potential real one and by head-tracking-contingent updating of the visual scene. Head tracking is important, because as head position changes in a real environment, the portion of it visible for the individual changes. In coming years, VEs will likely be commonplace both for training and familiarization purposes as in various types of simulators (e.g., for aircraft pilots) and for entertainment (e.g., games involving immersion and interaction).

With the broader introduction of more-realistic VEs, various problems are arising in terms of performance decrements during their use and in terms of aftereffects (DiZio and Lackner, 2002). This is to be expected. Virtual environments that allow immersion and "participation" so that the user can move about within them and manipulate objects violate many of the sensory-motor regularities characteristic of movement in a real environment. For example, in our normal environment, if a person makes a turn-and-reach movement to pick up an object or to point at something, a Coriolis force will be generated on the reaching arm that is proportional to the velocity of the arm and the rotational velocity of the torso (Pigeon et al., 2003). The reaches are nevertheless straight and accurate because the central nervous system anticipates and counteracts the effect of the Coriolis force (Figure 1). The Coriolis force arises on the arm because it is moving in the rotating frame of reference of the torso; its magnitude is proportional to the product of the velocity of trunk rotation and the linear velocity of the arm relative to the torso. By contrast, if a stationary individual is exposed to a VE that induces the sense of self-rotation and displacement, then in that case when reaching for or pointing to an object, the person will miss it (Cohn et al., 2000). The error results because the nervous system is correcting for the Coriolis force that would be generated if the individual were in fact rotating, but the correction is inappropriate. If the VE generates any experience of self-motion that does not exactly match the physical motion, there will be a mismatch between the automatically programmed Coriolis compensation and the physical Coriolis force present and the person will make reaching errors until they adapt to the new situation. Coriolis forces contingent on torso rotation are one of a large class of dynamic factors that can be mismatched in real and virtual environments. The greater the fidelity of the VE and the better the immersion of the subject, the greater the dynamic mismatch will be (DiZio and Lackner, 1992).

This example illustrates but one of the abnormal consequences of exposure to VEs that evoke the experience of self-motion. The user has to adapt to these environments because of the unusual and inappropriate patterns of sensory feedback associated with head and body movements. One consequence of the adaptation that can occur with prolonged exposure to VEs is the presence of aftereffects on return to the normal environment. These aftereffects can range from reaching errors to postural disequilibrium to flashbacks, with the latter being especially characteristic of exposure to flight simulators.

Some of the prominent side effects that occur in VEs are motion sickness and postural disequilibrium. The motion sickness symptoms elicited in VEs, in terms of their patterning and predominance, are highly dependent on the specific characteristics of the VE, such as the size of the field of view of view, the fidelity of the scene, whether the display is head tracked, and whether the VE is employed on stable ground or in a moving vehicle. The motion sickness elicited in virtual environments is often referred to as "cybersickness" (McCauley and Sharkey, 1992).

Postural disequilibrium can readily occur in VEs that involve apparent motion of the user or that involve head tracking to update the visual array (DiZio and Lackner, 1997). In VEs involving simulated motion of the user, the observer experiences body motion and as a consequence the nervous system initially makes postural adjustments for the experienced body motion as if it were real motion. Such compensations are inappropriate and can destabilize the body, which may trigger additional reflexive compensations that further exacerbate the situation. These problems are compounded in VEs that incorporate head tracking because of slow update rates and/or pure delays in updating the visual array. Such lag effects are always present in HMDs with head tracking, and the more complex and realistic the visual scene being depicted, the longer the associated time delays because of the greater computational complexity and computational time necessary to generate the scene. These time delays are rarely under 40 ms and often exceed 100 ms. If greater than about 25 ms, these lag effects have measurable adverse effects, and if greater than 50 ms, they have severe consequences. This is because when a user makes a gaze shift to fixate an object presented in the periphery of an HMD, it consists of two components, a saccadic eye movement to fixate the target and a head movement to orient the head to face the target. The eyes move first and acquire the target, and then the head starts turning. The rotation of the head will elicit a vestibuloocular reflex that normally acts to stabilize the eyes on the target by counterrotating the eyes relative to the head in pace with the head rotation. Without this compensation, the head movement would displace the eyes past the target. However, when a visual display is updated by head tracking, initially the scene will remain constant and then after a delay will be smoothly shifted in the direction opposite the motion of the head. The visual scene motion constitutes an optokinetic stimulus that along with the vestibulo-ocular reflex drives the eyes in the direction opposite the head movement so that they lose target fixation. The eyes make a rapid saccadic eye movement to regain fixation but are carried off target until scene updating is complete. What is normally a smooth coordinated pattern of eye and head movements becomes a disjointed pattern with multiple drifts and refixations, as shown in Figure 2.

If individuals are exposed to such scene updating contingent on their head movements for an extended period of time, they gradually adapt and their eye head coordination again becomes smooth and target fixation is maintained. However, on return to the normal environment, their eye-head coordination is again disrupted. These aftereffects are the consequence of the adaptive accommodations that were gradually made during exposure to the scene updating delays. As a consequence of the no-longer-appropriate compensations still occurring during head movements, eye-head coordination shows a pattern of sequential disruption that is mirror image to that which initially occurs during exposure. With repeated exposure to the updated virtual environments, subjects may eventually acquire a dual, context-specific adaptation such that they can move back and forth between the normal and the VE device without impairment of performance.

A prominent feature of the period before adaptation is achieved is the elicitation of symptoms characteristic of motion sickness. Until normal coordination of eye and head movements is regained, motion sickness symptoms will persist in susceptible individuals. On return to the normal environment after adaptation is complete, symptoms of motion sickness may recur with the renewed disruption of eye-head coordination. When dual context-specific adaptation is achieved, symptoms of motion sickness will no longer occur on transitions between the normal environment and the VE.

In general, the appearance and patterning of symptoms of motion sickness in exposure to VEs is that typical of exposure to relatively low-grade real motion environments—for example, the gentle rocking of a boat or ship (Kennedy et al., 1993). Head symptoms tend to predominate initially (e.g., drowsiness, eyestrain, headache and lack of initiative). With prolonged exposure, stomach awareness, discomfort, nausea and vomiting may also occur. Symptoms recede as adaptation occurs and then reappear on return to the normal environment. This pattern repeats until dual adaptation is achieved.

Not all VEs elicit symptoms of motion sickness. In experimental studies of motion sickness, it is common to expose seated individuals to whole-field visual stimulation. Figure 3 illustrates such a situation. A person is seated in a large drum that can be rotated to present a moving array of vertical stripes. Within about 5 to 30 seconds, the individual will experience compelling self-rotation and perceive the moving drum to be stationary. Most people within a few minutes will begin to experience symptoms of motion sickness that become progressively more severe with continued exposure. Some subjects will experience nausea and vomiting if the motion is not stopped. By contrast, if the same visual stimulation is delivered while an individual is walking in place on a treadmill that is rotating in the same direction and at the same velocity as the surrounding drum, then the individual will not experience symptoms of motion sickness even during extended exposure periods. Instead, within a few seconds, he or she will experience voluntary walking in a circle on a stationary platform in a stationary drum. In this circumstance, the pattern of visual stimulation the individual receives is appropriate for the experienced self-locomotion relative to the external world. In other words, the visual input received would correspond to that occurring with actual voluntary self-displacement. Normally, when we walk and displace in the real world the pattern of visual stimulation generated does not make us motion sick. We are adapted to this state. The important point is that in this type of VE that does not make individuals ill, there are voluntary stepping movements and concordant visual stimulation. There are no time delays involved and no issues related to head tracking. The patterning of sensory and motor activity is basically normal for the circumstances experienced.

Cybersickness bears many similarities with the sopite syndrome, a form of motion sickness that can arise with chronic exposure to relatively unprovocative physical motion, such as the gentle rocking of a boat. With frequent repeated or chronic long-term exposure to mildly provocative stimulation, a persistent form of motion sickness can develop involving drowsiness, apathy, lack of initiative, mood swings, headache, eyestrain, and postural instability. Chronic exposure to VEs that are provocative may lead to symptoms characteristic of the sopite syndrome and likely with continued exposure will elicit the full-fledged syndrome.

In discussions of cybersickness there is a tendency to concentrate on the motion sickness aspect. Astronauts in space flight also experience motion sickness, and on returning from space flight, symptoms may recur. Initially, this sickness was referred to as *space motion sickness*, but as further investigation showed, there was actually a complex pattern of changes and aftereffects that was occurring involving sensory-motor and postural control of the whole body. The constellation of effects became referred to as the *space adaptation syndrome* when it was recognized that not just motion sickness was involved. The constellation of effects observed during and after VE exposure shares many similarities with the space adaptation syndrome. The term *cyberadaptation syndrome* can appropriately be used to refer to the full set of behavioral, psychological and physiological changes that occur with exposure to virtual environments and the aftereffects that occur on return to the normal environment. A variety of adaptive changes will occur in VEs that will be specific to features of those environments; for example, if objects "fall" at a different rate in a VE than in the normal environment, then users will initially make errors in catching and intercepting objects on exposure to the VE and then again on return to normal circumstances. Symptoms of motion sickness and of the sopite syndrome will comprise the most prominent side effects of VEs involving head-tracking-contingent scene updating.

It can safely be anticipated that as new VEs are developed in which the users' participation generates unusual combinations of sensory and motor activity relative to the normal environment, new adaptive changes will occur that in turn will result in aftereffects that disturb normal performance.

1. See also

Motion sickness

Gravitational effects on brain and behavior

Vestibulo-ocular reflex (VOR)

2. Further reading

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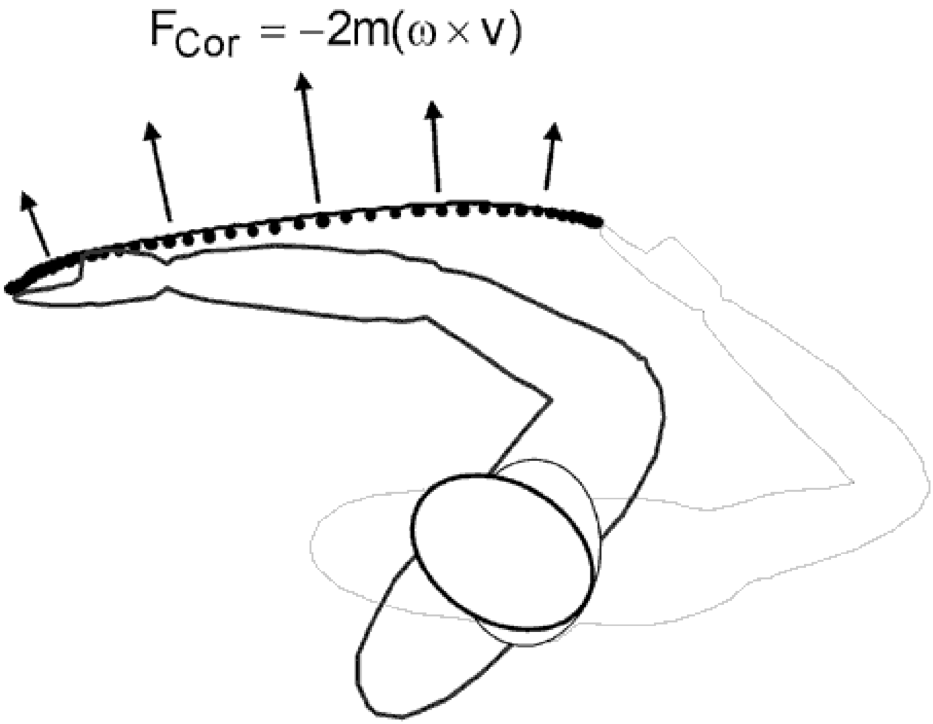

Figure 1. Coriolis forces (*arrows*) are generated when a subject reaches for a location that requires extension of the arm and rotation of the torso (light and dark lines represent the initial and final configurations, respectively). Although Coriolis forces scale with movement speed, there is no deviation of the path of the pointing finger in fast movements (*dots*) relative to slow movements (*solid line*).

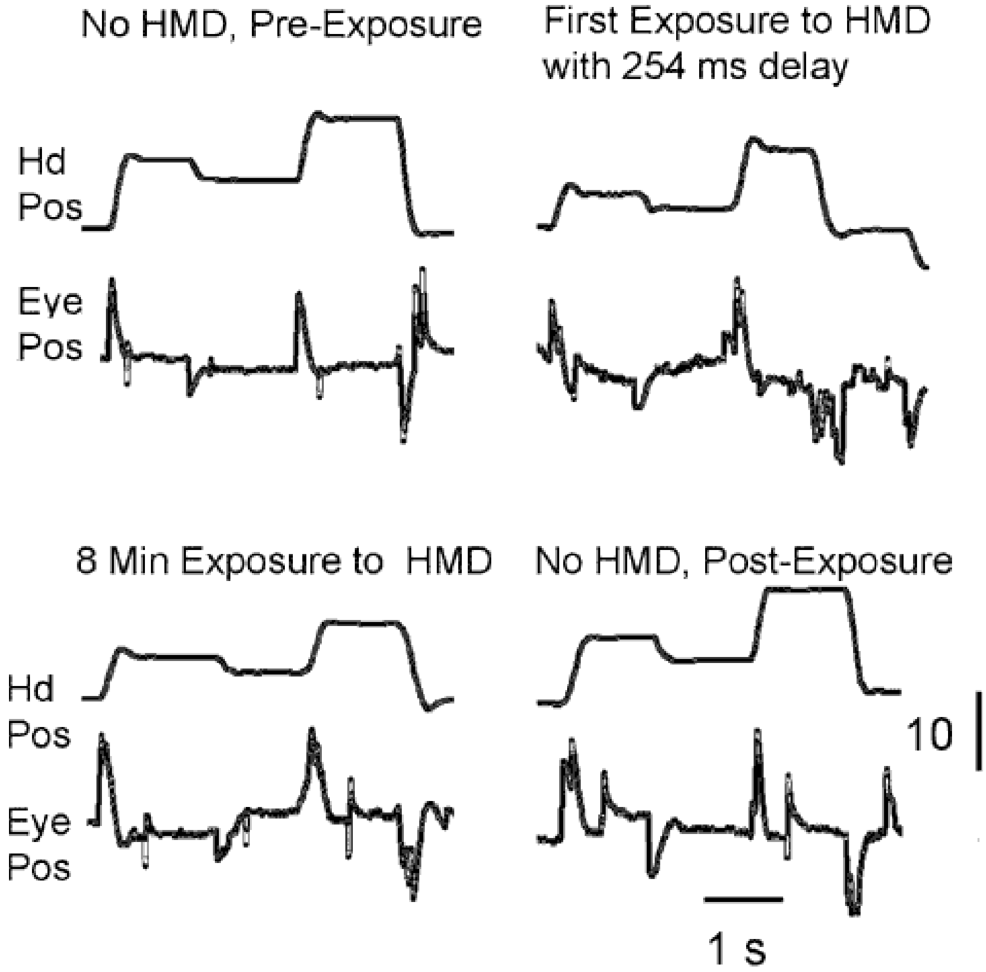

Figure 2. Illustration of head and eye movement coordination in a normal environment before exposure to a VE (*upper left*), during initial exposure to a VE incorporating a HMD with a 254 ms update delay relative to head movement onset (*upper right*), in the VE after 8 minutes of making a head movements (*lower left*), and back in a normal environment (*lower right*). The 10° vertical calibration bar refers to both the eye and head position signals.

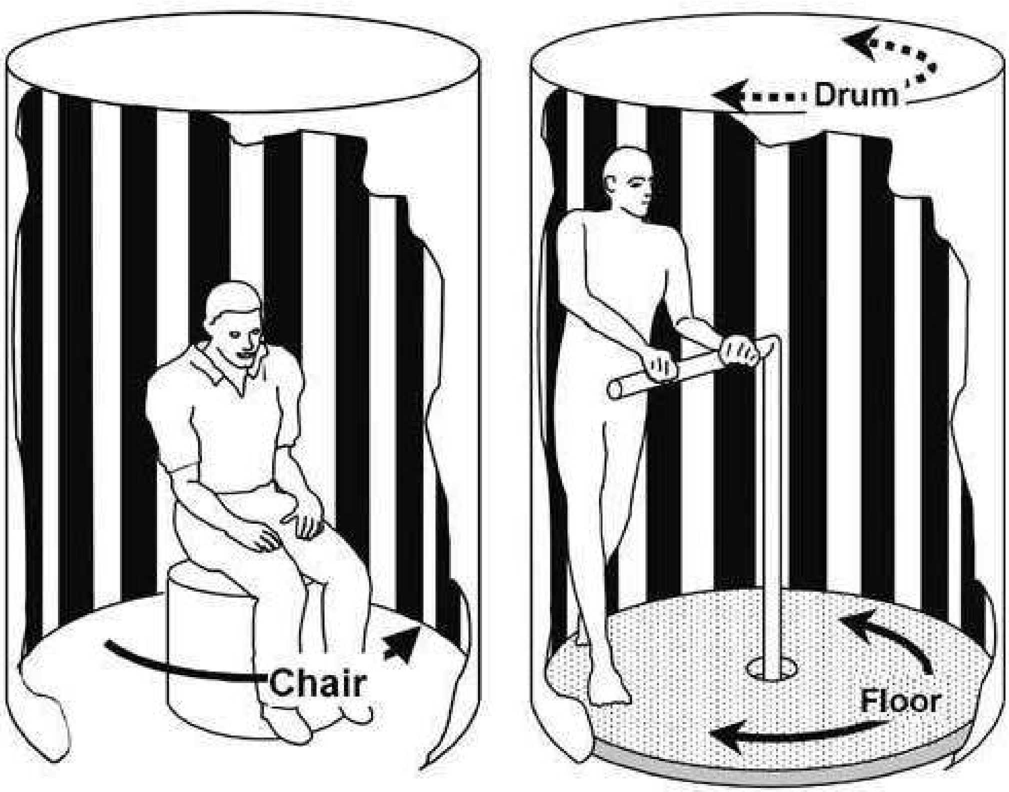

Figure 3. Left, Passive exposure to an optokinetic drum rapidly induces convincing virtual self-motion and motion sickness. Right, An inertially stationary subject stepping in place on a rotating floor in a rotating optokinetic drum experiences forward locomotion in a circle. Subjects rarely become motion sick.