L’effet de l’exposition aux stimuli olfactifs

sur le sentiment de présence en réalité virtuelle

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Résumé

Le sens de l’olfaction joue un rôle important dans la vie de tous les jours. Dans le monde physique (« réel »), les odeurs peuvent affecter l’humain de diverses manières. Bien que les avantages potentiels à intégrer des stimuli olfactifs dans des environnements virtuels (EV) aient été soulignés dans divers articles, ils sont rarement intégrés dans des applications de réalité virtuelle (RV). Les utilisations existantes et potentielles intégrant des stimuli olfactifs en RV incluent des applications cliniques tels le traitement des états de stress post-traumatique et le traitement d’addictions, des applications de formation telles que les réponses aux urgences et la relaxation, ainsi que des applications destinées à la recherche concernant les intégrations multisensorielles. Cependant, très peu d’études empiriques ont examiné les effets d’odeurs sur la qualité de l’expérience en RV. C’était l’objectif de ce projet. De façon plus précise, le but de ce projet était d’évaluer l’effet que peut avoir l’exposition à des odeurs agréable et désagréable sur les sentiments de présence (mesure principale), réalité et réalisme (mesures exploratoires) en RV.

Cette relation a été mise à l’épreuve dans le cadre de trois études complémentaires, chacune faisant appel à une condition contrôle (exposition à l’air ambiant) et deux conditions expérimentales (exposition à une odeur agréable de tarte aux pommes/cannelle ou une odeur désagréable d’urine). Alors que les trois études ont suivi le même protocole, la scène visuelle des EVs variait d’une étude à l’autre. Pour l’Étude 1, il n’y avait pas de concordance entre la scène visuelle et les odeurs, pour l’Étude 2, il y avait concordance entre la scène visuelle et l’odeur désagréable et pour l’Étude 3, il y avait concordance entre la scène visuelle et l’odeur agréable. La variation des EVs avait pour visée de vérifier l’effet de l’exposition aux odeurs sur la présence dans différentes conditions de concordance entre la scène visuelle et l’odeur.

L’ensemble des résultats révèle que, dans une situation sans concordance entre la scène visuelle et l’odeur, ainsi que dans une situation de concordance entre la scène visuelle et l’odeur désagréable, l'exposition à une odeur désagréable augmente le sentiment de présence de manière statistiquement significative. Lors d'une concordance visuelle avec une odeur désagréable, l'exposition à une odeur désagréable augmentait également la perception de réalité et réalisme de l'EV de manière statistiquement significative. De plus, dans un EV dont la scène visuelle est concordante avec une odeur agréable, l'exposition à une odeur agréable augmente le sens de la réalité de manière significative. Cependant, l'exposition à l'odeur agréable n'a pas eu d'effet sur le sentiment de présence, quel que soit le degré de concordance entre l'odeur et l'EV. Des résultats secondaires intéressants relatifs aux taux de détection consciente des odeurs ainsi que l'impact potentiel de ce taux sur l'effet des stimuli olfactifs ont été obtenus. Quelle que soit la concordance entre la scène visuelle et l'odeur, le taux de détection consciente de l'odeur désagréable n'était jamais en dessous de celui de l'odeur agréable. De plus, le taux de détection de chacune des odeurs était plus élevé lorsque la scène visuelle était concordante avec cette même odeur. Un regard sur l'ensemble des trois études indique que l'effet de l'exposition aux stimuli olfactifs sur les sentiments de présence et de réalité s'est manifesté uniquement lorsque le taux de détection consciente était supérieur à 59%. Lorsque, dans un EV concordant avec l'odeur désagréable, le taux de détection consciente de l'odeur atteignait 95% et l'exposition au stimulus olfactif augmentait les sentiments de présence, réalité et réalisme. L'ensemble des résultats suggère que l'exposition à un stimulus olfactif peut augmenter les sentiments de présence, réalité et réalisme, mais que la détection consciente de l'odeur joue un rôle important dans cette relation. Les retombées théoriques et pratiques de ces résultats sont discutées et des pistes de recherche future sont sugggérées.

Mots clefs : réalité virtuelle, présence, olfaction, odeurs, réalité, réalisme

Abstract

The sense of olfaction plays an important part in everyday life. In the physical (“real”) world, odours can affect humans in various ways. While the potential benefits of integrating olfactory stimuli in virtual environments (VE) have been theorized in numerous publications, this sort of stimulus is rarely integrated in virtual reality (VR) applications. Current and potential VR scenarios for integrating olfactory cues include clinical applications such as the treatment of post-traumatic stress disorder and drug addiction; training applications such as emergency response and relaxation; and research applications such as the investigation of multi-sensory integration. At the same time, very few empirical studies report on the effects of odours on the quality of the user experience in VR, which was the focus of this project. More specifically, to examine the effects of exposure to pleasant and unpleasant odours on the senses of Presence (primary measure), Reality, and Realism (exploratory measures) in VR.

The method consisted in verifying this relation over three studies, each using one control condition (exposure to ambient air) and two experimental conditions (exposure to a pleasant odour of cinnamon apple pie or to an unpleasant one of urine). While the three studies followed the same protocol, the visual scene of the VEs varied from one study to another. In Study 1, there was no particular concordance between the visual scene and either of the odours; in Study 2, there was concordance between the visual scene and the unpleasant odour; and in Study 3, there was concordance between the visual scene and the pleasant odour. The inter-study variation of the VE made it possible to verify the effect of the exposure to odours on Presence in varying conditions of visual/olfactory concordance.

The overall results suggested that, in neutral and visual/olfactory-concordant VEs, exposure to an unpleasant odour can significantly increase the sense of Presence. Furthermore, in a visual/olfactory-concordant VE, exposure to an unpleasant odour can also increase the senses of

Reality and Realism. In a visual/olfactory-concordant VE with a pleasant odour, exposure to that odour can increase the sense of Reality in a statistically significant manner. However, exposure to the pleasant odour had no statistically significant effect on Presence in any of the VEs. Interesting secondary results were obtained regarding the conscious detection rate of the odours and its potential role in the effect of the exposure to olfactory stimuli. Regardless of visual/olfactory concordance, the conscious detection rate of the unpleasant odour was never lower than that of the pleasant one. Furthermore, the conscious detection rate of each odour was higher when the visual scene was concordant with the odour. Looking across the results of the three studies, the effect of exposure to an olfactory stimulus on the senses of Presence and Reality only manifested itself when the conscious detection rate of the odour was at least 60%. When, in a VE concordant with the unpleasant odour, the conscious detection rate reached 95%, exposure to the olfactory stimulus increased the senses of Presence, Reality, and Realism. When combined, these results suggest that exposure to an olfactory stimulus can increase the senses of Presence, Reality, and Realism, but that conscious detection of the odour plays an important role in this relation. The practical implications of these results and potential follow-on studies are proposed.

Keywords: virtual reality, presence, olfaction, odours, reality, realism

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Format de la thèse

Cette thèse se compose d'une introduction générale, de quatre articles, ainsi que d'une discussion et conclusion générales. L'introduction porte sur la réalité virtuelle (RV) et la présence. Le premier article, *The Sense of Olfaction: Its Characteristics and its Possible Applications in Virtual Reality*, est une rescension documentaire sur l'olfaction, ce sens qui, malgré son importance, est encore sous-exploité dans le domaine de la réalité virtuelle. La suite de la thèse repose sur trois études expérimentales utilisant une méthodologie similaire afin d'examiner le rôle de différentes facettes des odeurs dans l'expérience vécue en RV. La première étude (Article 2), *Exposure to an Unpleasant Odour Increases the Sense of Presence in Virtual Reality*, examine le lien entre exposition à des stimuli olfactifs (agréable et désagréable) et les sentiments de présence (mesure principale), réalité et réalisme (mesures exploratoires). Ces relations ont été évaluées dans le cadre d'un environnement virtuel dépourvu d'objets manifestement liés à l'un, ou l'autre, des stimuli olfactifs. La seconde étude (Article 3), *In a Dirty Virtual Room. Exposure to an Unpleasant Odour Increases the Senses of Presence, Reality, and Realism*, examine les mêmes relations, mais dans le contexte d'un environnement virtuel concordant avec une odeur désagréable. Finalement, la troisième étude (Article 4), *Exposure to pleasant odour increases sense of Reality, but not senses of Presence or Realism,* examine ces mêmes liens, cette fois-ci, dans le contexte d'un environnement virtuel concordant avec l'odeur agréable. La thèse se termine par une conclusion qui intègre les principales informations dégagées des trois études.

Introduction générale

« Olfaction is one of the last barriers
that multimedia applications have to overcome
in order to truly engage a person's complete sensorial array. »
(Ghinea & Ademoye, 2011, p. 620)

Dans leur article, Ghinea et Ademoye (2011) rendent compte de ce qu'ils considèrent comme une lacune des systèmes actuels de réalité virtuelle (RV). Alors qu'il semble logique que l'ajout de stimuli olfactifs devrait mener à une expérience plus riche dans un environnement synthétique, très peu de publications abordent le sujet d'un point de vue empirique. Ce projet vise à quantifier l'effet que les stimuli olfactifs peuvent avoir sur l'expérience humaine dans un environnement virtuel (EV). Plus spécifiquement, l'objectif était de vérifier si, durant une immersion en RV, l'exposition à un stimulus olfactif aurait un effet sur le sentiment de présence de l'usager.

L'introduction de ce document servira à décrire ce qui définit la RV et présentera certaines de ces applications actuelles. Ensuite, le sentiment de présence, un des phénomènes centraux à l'expérience d'un EV, sera examiné en détail. De plus, afin de réduire les risques de confusion entre le sentiment de présence et d'autres phénomènes souvent mesurés en RV, certains de ces derniers seront définis et différenciés entre eux. Ensuite, l'importance du sentiment de présence ainsi que les diverses manières, objectives et subjectives, de le mesurer seront abordées en détail. Puis, des variables individuelles et environnementales pouvant influer sur le sentiment de présence seront présentées. L'intérêt potentiel d'intégrer des stimuli olfactifs dans les EV sera justifié en rapportant, brièvement, certains des effets qu'ont les odeurs sur l'humain dans le monde non synthétique. La septième partie du texte décrira quelques-uns des EV intégrant déjà des stimuli olfactifs. Ensuite, les rarissimes publications ayant étudié l'effet de stimuli olfactifs sur le sentiment de présence seront examinées, ainsi que critiquées. Finalement, l'hypothèse de recherche de ce projet sera énoncée.

La Réalité Virtuelle

Définitions. Un environnement virtuel (EV) se définit comme un espace numérique tridimensionnel avec lequel un utilisateur peut interagir (p. ex., le scénario d'un jeu vidéo; Baus & Bouchard, 2014). Généralement, il est constitué, au minimum, de stimuli visuels projetés sur une plateforme (p. ex., écran d'ordinateur, visiocasque, ou murs de voûte immersive, etc.) et son utilité consiste à remplacer les stimuli du monde non synthétique avec des stimuli digitaux (Fox, Arena, & Bailenson, 2009). En plus des stimuli visuels, un EV peut également exposer l'utilisateur à des stimuli acoustiques, haptiques, olfactifs ou même gustatifs (Burdea & Coiffet, 1994; Fuchs, Moreau, Burkhardt, & Coquillart, 2006; Kalawsky, 1993; Sundgren, Winquist, & Lundstrom, 1992).

La réalité virtuelle (RV) se définit comme une application permettant à un utilisateur d'interagir, en temps réel, avec un EV (Pratt, Zyda, & Kellecher, 1995). À l'intérieur de ce dernier, et en fonction de la complexité du système, un utilisateur peut se déplacer (ou déplacer une représentation virtuelle de lui-même, nommée « avatar »), ainsi qu'interagir avec un espace virtuel, des objets virtuels, ou même des personnages virtuels. Les actions de l'utilisateur sont suivies par un ordinateur qui génère et déploie les stimuli appropriés en temps réel (images, sons, etc.). Comparés à ceux des médias plus passifs tels que la radio et la télévision, les hauts degrés d'interactivité cognitive, sociale et physique de la RV peuvent accroître les effets de l'expérience de l'EV sur l'utilisateur (Fox, Arena, & Bailenson, 2009).

Équipement de base. Le plus souvent, l'usager est exposé aux stimuli visuels d'un EV par le biais d'un visiocasque ou d'une voûte immersive. Un visiocasque est composé de deux écrans vidéo de la taille d'une lunette (certains modèles intègrent également des écouteurs). Pour exposer l'utilisateur à l'EV, les images sont projetées, souvent en stéréoscopie, sur ces écrans. Dans le cas de certains visiocasques, la vue de l'utilisateur est isolée de l'environnement non synthétique, il ne peut donc percevoir que les images sur les écrans. Le visiocasque peut également être muni d'un capteur de localisation permettant aux images d'être ajustées selon les mouvements de tête de l'utilisateur. Quant à la voûte immersive, elle expose l'usager à l'EV par le biais d'une rétroprojection d'images sur un nombre variable de surfaces (p. ex., un cube de six écrans de projection de 10 X 10 X 10 pieds). Durant une immersion, un utilisateur se place à l'intérieur de ce cube, et grâce à des lunettes de stéréoscopie passive ou active, il peut percevoir l'EV en stéréoscopie. Ces lunettes sont généralement munies d'un capteur de localisation permettant ainsi aux images d'être ajustées selon les mouvements de l'utilisateur. Les avantages dont jouit la voûte immersive sur le visiocasque incluent le port d'un équipement moins encombrant, ainsi que la possibilité de voir son propre corps évoluer dans l'EV. Les avantages d'un visiocasque incluent ses coûts beaucoup plus abordables, la portabilité, et la possibilité d'être utilisé dans des espaces de la taille d'un bureau.

Un utilisateur interagit avec l'EV, au moins en partie, par le biais des mouvements de son propre corps. Afin que le système puisse suivre ses mouvements, l'utilisateur porte un (parfois plusieurs) capteur de localisation (généralement, au niveau de la tête). Ce dernier détecte sa propre position dans l'espace et la transmet continuellement à un ordinateur qui lui, utilise la base de données spécifique à la scène pour mettre à jour les images, en temps réel. Un capteur de localisation peut comporter trois degrés de liberté (« *three dof* ») ou six degrés de liberté (« *six dof* »); ils permettent, respectivement, le suivi du mouvement de rotation de la tête ou les suivis de rotation de la tête et des déplacements (en horizontal et en vertical). Généralement, l'utilisateur d'un système avec six degrés de liberté complète les petits mouvements du corps (se tourner, se baisser, se repositionner, etc.) comme dans un environnement non synthétique, mais actionne une manette électronique pour « marcher » dans l'EV (tel que dans un jeu vidéo). Dépendant du type de système et de la programmation, l'utilisateur interagit avec l'environnement d'un point de vue égocentrique (il voit la scène du point vue de sa position et de son orientation dans l'EV) ou allocentrique (il voit son avatar évoluer dans l'EV).

Applications de la réalité virtuelle. De nos jours, la RV est utilisée entre autres, pour la formation, l'éducation, les soins de santé, la communication, l'ingénierie et le divertissement (Schuemie, 2003). Dans un cadre de formation/entraînement, la RV peut offrir, à moindres coûts, un apprentissage expérientiel et actif par le biais de scénarios parfois trop difficiles ou dangereux à reproduire dans le monde non synthétique. L'interactivité de la RV (Bailenson et al., 2005) ainsi que la possibilité de préprogrammer des scénarios pour des utilisateurs à divers niveaux de compétence peuvent faciliter un meilleur apprentissage. D'ailleurs, l'apprentissage, la sécurité, ainsi que les coûts réduits font partie des arguments principaux des applications actuelles et potentielles de la RV. Ces applications incluent l'apprentissage de : l'opération de divers véhicules (p. ex., Tichon, Wallis, & Mildred, 2006); l'inspection visuelle d'avion avec fautes structurelles variées (p. ex., Vora et al., 2002); les prises de décision rapide et efficace de médecins (p. ex., de Leo et al., 2003; Johnsen et al., 2006; Kenny, Rizzo, Parsons, Gratch, & Swartout, 2007; Mantovani, Castelnuovo, Gaggioli, & Riva, 2003) et de soldats (p. ex., Hill et al., 2003) en situation de stress; la gestion d'urgences médicales (p. ex., Viciana-Abad, Reyes-Lecuona, García-Berdonés, & Díaz-Estrella, 2004); la communication interculturelle avant le déploiement de soldats à l'étranger (p. ex., Deaton et al., 2005); la gestion du stress (p. ex., Bouchard, 2010)**;** divers sujets théoriques tels que l'anatomie humaine (p. ex., O'Toole et al., 1998; Spitzer & Ackerman, 2008)**;** diverses procédures chirurgicales (p. ex., Harders et al., 2008; O'Toole et al., 1998; Spitzer & Ackerman, 2008); réactions non phobiques à des stimuli phobogènes (p. ex., Côté & Bouchard, 2005).

La RV peut également être utilisée par des applications autres que celles destinées à la formation. Celles-ci incluent : la gestion de la douleur par le biais de la distraction (Gold, Belmont, & Thomas, 2007; Hoffman et al., 2008); la visualisation et la visite de bâtiments en phase de conception (Brooks et al., 1992), la conception de salles de classe virtuelles (Moreno & Mayer, 2007), de lieux de travail virtuels (Wilson & D'Cruz, 2006) ou d'environnements collaboratifs de travail permettant l'interaction par le biais d'avatars (Benford, Greenhalgh, Rodden, & Pycock, 2001; Joslin, Di Giacomo, & Magnenat-Thalmann, 2004; Normand et al., 1999; Reeves, Malone, & O'Driscoll, 2008); et le traitement de certains troubles psychologiques (p. ex., Rothbaum, Rizzo, & Difede, 2010).

Le Sentiment de Présence

Pour le but des applications ci-dessus, il serait utile que l'EV ait la capacité d'activer les pensées, émotions et comportements semblables à ceux qu'un même environnement, lui non synthétique, activerait. Cette capacité est liée à l'impression de l'utilisateur de vraiment se mouvoir dans cet environnement qui, en réalité, n'est qu'une construction de stimuli synthétiques. Certains auteurs désignent cette impression de se sentir dans l'EV comme le sentiment de « présence ». Bien que le sentiment de présence soit présenté ici en association à la RV, d'autres médias tels que le cinéma, la télévision, le théâtre, la peinture, la lecture, ou même la radio peuvent également évoquer un sentiment de présence (Nash, Edwards, Thompson, & Barfield, 2000).

Le terme « présence » tire son origine du sentiment de « Téléprésence » (Minsky, 1980). Avant que les systèmes informatiques aient la puissance de calcul nécessaire pour créer des EV, la technologie de communication permettait déjà à un utilisateur d'opérer un robot à distance (p. ex., un robot tactique de déminage). Par le biais d'une caméra montée sur le robot, d'un écran diffusant l'image de la caméra et d'un système de télécommande, l'opérateur voit l'environnement immédiat du robot et actionne les parties essentielles à son opération. En conséquence, l'opérateur peut avoir l'impression de « s'incarner » dans le robot (Sanchez-Vives & Slater, 2005). Selon sa définition d'origine, le terme « Téléprésence » sous-entend un sentiment de se sentir dans un lieu distant, mais réel, visionné par le biais de prises de vue animées. La motivation initiale des recherches sur la Téléprésence était basée sur l'hypothèse qu'un sentiment de Téléprésence accru pourrait améliorer la performance de l'opérateur (Sheridan, 1992). Selon Riley (2001), ce domaine de recherche aurait contribué au développement de robots plus anthropomorphiques, ainsi qu'à des améliorations aux intégrations homme-système (p. ex., des écrans de haute-fidélité, la transmission des stimuli auditifs sur scène, la rétroaction haptique). Avec l'apparition de la RV, un concept dérivé du sentiment de Téléprésence fit son apparition : le sentiment de « présence ». Alors que le premier est associé à la téléopération d'un robot dans un lieu réel, mais distant, le second est associé au repositionnement de l'usager dans un lieu virtuel; ce lieu étant virtuel, il n'est ni proche ni distant. Malheureusement, les définitions exactes du terme « présence » ainsi que ses potentielles sous-catégories sont nombreuses. Elles incluent : la « présence virtuelle » (Sheridan, 1992), la « présence spatiale » (Lessiter, Freeman, Keogh, & Davidoff, 2001; Schubert, Friedmann, & Regenbrecht, 2001), et la « présence physique » (Lee, 2004).

Dans l'ensemble, deux idées dominantes décrivent le processus qui mènerait au phénomène de présence en RV. La première lie le sentiment de présence à « l'illusion perceptuelle de la non-médiation » (Lombard & Ditton, 1997) : l'usager perd conscience des soutiens technologiques (écrans, visiocasque, ordinateurs, etc.) et a l'impression d'évoluer dans le monde virtuel (Lombard & Ditton, 1997). Selon la seconde, le sentiment de présence serait lié aux réponses appropriées de l'EV face aux actions de l'usager (« *successfully supported actions* »; Zahoric & Jenison, 1998); une réponse est considérée comme appropriée lorsqu'elle obéit aux règles du monde non synthétique (Schuemie, 2003). Cette approche met l'accent sur les actions que peut entreprendre l'usager. Le sentiment de se sentir *là* est lié à la possibilité d'agir, *là* (Slater, 2004). Ce point de vue sous-entend que le réalisme de la scène visuelle est moins important que la mesure dans laquelle l'usager peut entreprendre les actions souhaitées (Chertoff, Schatz, McDaniel, & Bowers, 2008); cette conception s'apparente à celle de la « présence incarnée » (« *embodied presence* ») de Schubert, Friedmann, et Regenbrecht (2001), et elle rejoint la conception qu'il est important d'avoir une bonne correspondance entre les stimuli de l'EV et la proprioception kinesthésique (Slater, Usoh, & Steed, 1995). Cette même vision est partagée par Biocca (1997) qui propose que le fait qu'un EV engage plusieurs sens facilite l'engagement sensoriel, moteur et sensorimoteur.

Même s'il n'y a pas de consensus sur la nature exacte de la présence, il y en a un autour de certains de ses attributs; le sentiment de présence est : (a) un construit multidimensionnel composé de divers sous-types de présence (p. ex., IJsselsteijn & Harper, 2001; Kalawsky, 2000); (b) une « réponse » aux propriétés immersives d'un système (p. ex., Slater, Lotto, Arnold, & Sanchez-Vives, 2009); (c) le résultat d'une interaction entre les stimuli émis par le média et les facteurs internes de l'usager (pensée, émotions, cognitions, comportements; p. ex., IJsselsteijn &

Harper, 2001; Schubert, Friedmann, & Regenbrecht, 2001); et (d) un indicateur du degré de réponse qu'évoque l'EV chez l'usager (p. ex., Schuemie, 2003).

En guise de définition du sentiment de présence, la conception proposée par Heeter (1992) servira de référence au présent projet. Selon cette auteure, le sentiment de présence se définit comme un sentiment complexe composé de trois dimensions : la présence personnelle, la présence environnementale et la présence sociale (Heeter, 1992). La présence personnelle (parfois appelée présence physique ou virtuelle) se définit comme l'impression d'être à l'intérieur de l'EV (Heeter, 1992). C'est l'impression d'exister dans, de faire partie de, l'EV (Schuemie, 2003). Dans les publications, le terme « présence » est souvent utilisé comme synonyme à la présence personnelle (Sadowsky & Stanney, 2002); ce sera également le cas pour le présent projet. La présence environnementale se définit comme le degré selon lequel l'EV semble reconnaitre la présence de l'usager et réagit à ses actions (Heeter, 1992). Jerome et Jordan (2007) la décrivent comme le degré de réaction aux perturbations causées par l'usager (p. ex., les changements de taille, forme et position de l'ombre d'un objet virtuel durant le déplacement de ce dernier par l'usager). Le degré de cohérence avec lequel l'environnement répond aux actions de l'usager agit comme un des facteurs liés au degré de présence environnementale (Jerome et Jordan, 2007). Le modèle de Heeter (1992) intègre également la notion d'une représentation du soi d'un point de vue social. La présence sociale fait référence à l'impression de ne pas se sentir seul, d'être en relation avec d'autres êtres (réels ou virtuels) dans l'EV (Heeter, 1992). Elle est liée à la saillance de l'être, au degré d'interaction, ainsi qu'à l'immédiateté (« *immediacy* ») et l'intimité (« *intimacy* »; Heeter, 1992; Shin, 2002). Alors que l'immédiateté mesure la distance sociale et peut être augmentée par des comportements immédiats tels que les hochements de tête et les sourires (Short, Williams, & Christie, 1976), le degré d'intimité est ajusté de manière consciente en réaction à la justesse de l'interaction (Jerome & Jordan, 2007). La présence sociale peut donc être influencée par le contexte de l'interaction, la parole, ainsi qu'une foule d'indices verbaux et non verbaux (Rice, 1993). Elle incarne, en quelque sorte, une variation de la présence environnementale : au lieu de simplement avoir l'impression d'interagir avec l'EV selon des lois physiques, l'usager à l'impression d'interagir avec des êtres selon des lois sociales. Ces êtres, tout en étant animés d'un certain degré d'autodétermination, semblent réagir aux actions de l'usager. Un degré supérieur de présence sociale se caractérise par un sens plus profond d'engagement psychologique, d'accès et de connexion aux états cognitif et affectif du vis-à-vis (Jerome & Jordan, 2007); il sous-entend un engagement comportemental durant lequel les actions sont liées, réactives et interdépendantes (Biocca, Harms, & Gregg, 2001).

À ce point-ci, il est utile de souligner la distinction qui doit être faite entre les concepts de présence et d'Immersion. Selon Slater et Wilbur (1995), l'Immersion est un aspect quantifiable de la technologie composée de facteurs tels que : (a) le degré d'isolation de l'usager des stimuli du monde non synthétique, (b) le nombre de modalités sensorielles auxquelles l'usager est exposé, (c) la taille panoramique des écrans, et (d) la résolution des écrans. À ces facteurs, Slater (2003) ajoute : la qualité des stimuli auxquels le système expose l'usager, ainsi que par la précision du suivi de la position de l'usager dans l'EV. Le degré d'Immersion est donc une propriété objective du système de RV (Sanchez-Vives & Slater, 2005). Le sentiment de présence, quant à lui, est en quelque sorte l'homologue expérientiel du degré d'Immersion (Ijsselstein, 2002); c'est une réaction de l'usager à l'immersion (Slater, Lotto, Arnold, & Sanchez-Vives, 2009). Il existe manifestement un lien entre l'Immersion et la présence, mais un même degré d'Immersion peut évoquer deux degrés de présence différents chez deux usagers. De même, deux systèmes aux propriétés immersives inégales peuvent induire un même degré de présence chez deux usagers (Slater, Lotto, Arnold, & Sanchez-Vives, 2009). Ces variances sont liées au rôle des facteurs individuels dans le sentiment de présence (p. ex., l'imagination, les expériences passées, l'humeur, la nature du stimulus; Heeter, 2003). En somme, la présence représente un facteur psychologique alors que l'Immersion représente un facteur technologique, lui-même facilitateur de l'expérience du sentiment de présence (Thornson, Goldiez, & Le, 2009);

Les sentiments de Réalisme et Réalité

Deux autres concepts importants à distinguer du sentiment de présence, ainsi qu'entre eux, sont les sentiments de réalisme (« realism ») et de réalité (« reality »). Tout comme le sentiment de présence, leurs degrés sont subjectifs et peuvent donc varier entre usagers. Dans le cas du réalisme, il correspond à une évaluation des stimuli. Il semble étroitement lié au degré de convergence entre l'expérience vécue et les attentes de l'individu (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000). Cela sous-entend que, dans le contexte d'une immersion en RV, un stimulus conforme aux attentes de l'usager (p. ex., une orange qui sent l'orange) risque d'être interprété comme plus réaliste qu'un stimulus ressemblant moins au modèle de référence (p. ex., une orange qui sent le poisson); il reste que c'est la concordance des mondes non synthétique et synthétique telle qu'évaluée par l'usager, et non une concordance objective, qui détermine le degré de réalisme. Le degré de réalité, quant à lui, fait référence au degré auquel l'usager vit l'expérience en RV comme véridique (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000). Il correspond à un ressenti en réponse aux stimuli et selon Steuer (1995), il serait lié à la volonté de suspendre l'incrédulité (« *willing suspension of disbelief* »). Intuitivement, on s'attendrait à ce qu'un degré élevé de réalisme doive promouvoir un degré élevé de réalité. Cependant, la scène visuelle d'un EV pourrait très bien ne pas ressembler au monde tel que l'usager le connaît (un degré de réalisme peu élevé), mais être vécue comme une expérience réelle (un degré de jugement de réalité élevé).

L'Importance du Sentiment de Présence en RV

L'atteinte d'un certain degré de présence favorise l'expérience d'un EV (Aymerich-Franch, 2010) et contribue à la possibilité de faire vivre à l'usager une expérience similaire à celle qui serait vécue dans le monde non synthétique. Le sentiment de présence est donc un élément important de l'expérience en RV (Bouchard, St-Jacques, Robillard, & Renaud, 2008) et il peut agir comme facilitateur dans l'accomplissement du but d'un EV (van Schaik, Turnbull, van Wersch, & Drummond, 2004). S'y intéresser paraît pertinent pour plusieurs domaines tels que la formation, le divertissement, les arts, et certains services de santé. Comme déjà mentionné, la RV peut offrir un apprentissage expérientiel et actif, par le biais de scénarios difficiles ou trop dangereux à reproduire dans le monde non synthétique, et cela, à des degrés de difficulté adaptés aux compétences de l'utilisateur. Dans ce processus d'apprentissage, un degré élevé de présence rend l'expérience engageante ainsi que pertinente (Mantovani & Castelnuovo, 2003). Il peut déclencher les pensées, émotions et comportements similaires à ceux déclenchés dans l'environnement non synthétique, permettant ainsi la création d'une expérience dont les apprentissages pourront être remémorés par le biais d'associations (Mantovani & Castelnuovo, 2003). De plus, un degré élevé de présence peut augmenter la motivation à apprendre (Heeter, 2003). Son importance dépasse donc l'expérience elle-même, car le fait de se sentir présent dans un scénario peut améliorer l'apprentissage (Schank, 1997). Il ouvre également la porte à des études fondamentales dans des situations que, dans le monde non synthétique, on ne peut simuler ou répéter de manière identique pour chaque participant (Lombard & Ditton, 1997). En conséquence, le sentiment de présence est devenu un sujet de recherche d'intérêt à la fois théorique et pratique.

Mesurer le Sentiment de Présence

Considérations Générales. La question fondamentale à laquelle répond le sentiment de présence est d'indiquer à quel point l'usager se sent dans l'EV. Bien que la communauté scientifique s'accorde sur l'importance d'un tel construit pour mesurer la qualité de l'expérience en RV, les divergences sur sa définition exacte ont mené à l'absence d'un consensus sur la manière de le mesurer (Lombard et al., 2000; Zahorik & Jenison, 1998). La difficulté à mesurer le sentiment de présence est accentuée par sa nature même. En effet, quelle que soit la définition, il correspond à un état expérientiel dynamique susceptible à des variations intra-individuelles; essentiellement, c'est un paramètre cognitif et perceptuel (Kalawsky, 2000) variant d'un moment à l'autre selon les buts de l'individu (Jerome & Jordan, 2007). Diverses méthodes ont donc été déployées pour le mesurer. Dans l'ensemble, ces mesures ont recours à deux types d'indicateurs : des indicateurs objectifs (p. ex., observation du comportement et réactions physiologiques) et des indicateurs subjectifs (p. ex., mesures verbales prises durant immersion et questionnaires post-immersion).

Les Indicateurs Objectifs du Sentiment de Présence. Les mesures objectives du sentiment de présence font appel à des réponses observables de l'usager durant l'immersion. Celles-ci peuvent être, entre autres, des réactions physiologiques (p. ex., les rythmes cardiaques et de circulation sanguine, la conductance cutanée, la pression sanguine, la tension musculaire, les réponses oculaires, l'activité du cerveau, etc.) ou des comportements (p. ex., mouvements, posture, etc.; Thornson, Goldiez, & Le, 2009). Un instrument de mesure objectif de présence établit le degré de similitude entre les réactions *in vivo* (« *ground-truth* ») et celles *in virtuo*

(Meehan, Insko, Whitton, & Brooks, 2002; Sanchez-Vives & Slater, 2005; Slater, 2004; Slater & Wilbur, 1997). Par exemple, Bideau et collègues (2003) ont comparé les réactions à des lancés de balle *in virtuo* à celles de lancés de balle *in vivo*, alors que Jordan et Slater (2009) ont comparé les mouvements oculaires *in virtuo* avec ceux *in vivo*. Un des avantages des mesures objectives se manifeste par un assujettissement moins important à certains biais associés aux mesures autorapportées (p. ex., mémoire et désirabilité sociale; Thornson, Goldiez, & Le, 2009). En même temps, pour en démontrer la validité, il faut prouver une absence de différence entre les réactions *in vivo* et *in virtuo*; cela constitue un défi méthodologique important.

Les mesures physiologiques.

Bien qu'elles puissent s'avérer utiles, l'utilisation de mesures physiologiques comme mesure de présence doit être faite avec réserve. Sheridan (1992) va même jusqu'à dire que, la présence étant une sensation subjective, c'est une manifestation mentale et elle ne peut être mesurée par la physiologie. En fait, le rythme cardiaque et la conductance cutanée corrèlent avec le stress et les émotions de l'usager (Kecklund & Åkerstedt, 2004), et non pas avec le sentiment de présence en tant que tel. Cependant, ces mesures physiologiques pourraient peut-être servir d'indicateur indirect du sentiment de présence si les réactions physiologiques sont manifestement liées au scénario de l'EV. Spécifiquement, dans une scène virtuelle capable d'évoquer un stress (p. ex., l'usager doit éteindre un feu dans un appartement), des mesures physiologiques associées au stress pourraient peut-être servir d'indicateur de présence (si l'usager ressent un stress, alors il se sent probablement présent). C'est d'ailleurs ce qu'ont trouvé certains chercheurs. En plaçant cinq participants dans un scénario d'aviophobie, Wiederhold et collègues (1998) ont observé une corrélation entre la conductance cutanée et le sentiment de présence. Dans un scénario d'acrophobie, Meehan, Insko, Whitton, et Brooks (2002) ont constaté une corrélation entre le sentiment de présence, le rythme cardiaque et la conductance cutanée (mais pas avec la température de la peau), on peut détecter. Par contre, dans des scénarios moins susceptibles d'évoquer des émotions fortes (p. ex., la simple visite d'un appartement virtuel), l'utilisation de mesures physiologiques comme indicateur du sentiment de présence pourrait être inappropriée (Slater, 2004).

Les mesures comportementales. Toute action indiquant que l'EV agit sur l'usager pourrait potentiellement servir d'indicateur comportemental de présence (p. ex., l'usager essaye de saisir un objet virtuel, fait le tour d'un obstacle virtuel, converse avec un agent virtuel). Les mesures comportementales de présence incluent : les réflexes défensifs tels que le clignement des yeux (Held & Durlach, 1992; Nichols, Haldane, & Wilson, 2000), l'identification de la source d'un son dans l'EV (Slater, Usoh, & Chrysanthou, 1995), les réactions physiques à des évènements inattendus (Slater et Wilbur, 1997), les expressions faciales (Huang & Alessi, 1999), les changements de posture en réponse à des stimuli de mouvement (Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000), et les réponses de nature sociale (Bailenson, Blascovich, Beall, & Loomis, 2003).

Cependant, tout comme les réactions physiologiques, la validité de comportements en guise d'indicateur de présence doit être déterminée avec prudence. En effet, un réflexe défensif (p. ex., cligner des yeux) pourrait ne pas être un indicateur valide de présence, car il ne suggère pas nécessairement une conscience de l'environnement avant l'évènement déclenchant le réflexe. Par exemple, un individu assis à un bureau, en pleine rêverie (donc peu présent), risque quand même d'avoir le réflexe d'éviter un objet qui apparait soudainement dans son champ visuel sur une trajectoire de collision avec sa tête. Par contre, le réflexe d'essayer d'attraper une balle virtuelle qu'un personnage virtuel lance soudainement à l'usager pourrait être un meilleur indicateur de présence. En effet, cet acte sous-entend une meilleure conscience de l'environnement et un choix conscient d'agir (le choix d'attraper l'objet serait peut-être différent s'il s'agissait d'un couteau). En même temps, l'absence d'un comportement n'indique pas nécessairement une absence de présence. Par exemple, le fait qu'un usager marche « à travers » une table virtuelle peut aussi bien indiquer un manque de présence qu'un degré élevé de distraction. La relation entre les comportements sociaux et le sentiment de présence peut également s'avérer difficile à établir par la seule observation du comportement. Par exemple, un usager extraverti peut démontrer un sentiment de présence élevé en interpellant un personnage virtuel, alors qu'un usager introverti peut démontrer un sentiment de présence tout aussi élevé, sinon plus, en n'interpellant justement pas le personnage virtuel. Compte tenu des limites des mesures objectives, ainsi que la nature subjective du sentiment présence, il semble risqué de le mesurer uniquement par des indicateurs objectifs (Sheridan, 1992).

Les indicateurs subjectifs du sentiment de présence. Ainsi, le sentiment de présence se mesure le plus couramment par le biais de mesures subjectives (Juan & Pérez, 2009). Ces dernières impliquent des mesures autorapportées et leur avantage principal se caractérise par l'opportunité qu'elles offrent à l'individu de rendre compte de son expérience dans l'EV (Mosbruger, 2003). Compte tenu de la nature psychologique du sentiment de présence, cette démarche semble être un élément essentiel de la quantification du phénomène. Bien que différentes méthodes de mesure subjective soient utilisées, les mesures prises durant l'immersion et les questionnaires post-immersion sont parmi les plus populaires. Comparés aux mesures objectives, ces instruments de mesure sont peu dispendieux ainsi que faciles à administrer et interpréter (Thornson, Goldiez, & Le, 2009). Par contre, dû en partie aux différentes définitions du concept, de nombreux questionnaires ont été développés pour les besoins particuliers de certains chercheurs. Ainsi, la diversité des instruments de mesure subjectifs rend les comparaisons interexpérimentales difficiles (Thornson, Goldiez, & Le, 2009). Malgré cette diversité, certains questionnaires ont bénéficié d'une plus grande visibilité dans le champ de la recherche sur la présence. Le questionnaire Slater-Usoh-Steed (SUS; Slater, Usoh, & Steed, 1994), constitué de six items dans sa dernière version, quantifie le degré de présence selon les trois facteurs suivants : la sensation d'être là, la sensation que l'EV devient plus réel et « présent » que le monde non synthétique, ainsi que la sensation que l'EV représente un lieu réel plutôt qu'une construction d'images. Le questionnaire de présence de Kim et Biocca (1997), composé de huit items, utilise les facteurs de « départ » et « arrivée » entre les mondes non synthétique et virtuel pour quantifier la présence. Witmer et Singer (1998) identifient l'engagement et l'immersion comme conditions nécessaires du sentiment de présence. Ainsi, leur « *Presence Questionnaire* » (PQ; Witmer & Singer, 1998), dont la dernière version est constituée de 19 items, mesure quatre facteurs qui influent sur ces conditions : le degré de contrôle de l'usager sur les évènements dans l'EV, le degré de stimuli sensoriels virtuels (la qualité, le nombre, etc.), le degré de distraction agissant aux dépens de l'EV, et le réalisme de l'EV. Le Igroup Presence Questionnaire (IPQ; Schubert, Friedman, & Regenbrecht, 1999, 2001) utilise 14 items pour mesurer cinq facteurs liés à l'immersion et les trois facteurs suivants liés à la présence : la présence spatiale, l'engagement, et le degré de réalité. Le « *ITC Sense Of Presence Inventory* » (ITC-SOPI; Lessiter, Freeman, Keogh, & Davidoff, 2001) de 44 items mesure les quatre facteurs de présence suivant : l'impression d'occuper un espace physique, l'engagement, la validité écologique et les effets négatifs. Finalement, le Temple Presence Inventory (TPI; Lombard, Ditton, & Weinstein, 2009) vaut également la peine d'être mentionné. Bien que sa publication récente ne lui permette pas d'avoir le même statut que les autres questionnaires ci-dessus, la structure du TPI, basée sur une des conceptualisations les plus complètes du sentiment de présence (tirée de Lombard et Ditton, 1997), lui a le mérite d'être mentionné ici. De plus, il appartient au groupe restreint de questionnaires mesurant également la présence sociale. Composé de 42 items, le TPI mesure huit facteurs de présence : la présence spatiale, la présence sociale (acteur), la présence sociale active, la présence sociale passive, l'engagement, la richesse sociale, le réalisme social et le réalisme perceptuel. Des six questionnaires ci-dessus, le SUS et le PQ sont les plus utilisés et ils ont servi de base pour l'élaboration d'autres questionnaires (Lombard, Ditton, & Weinstein, 2009). Par exemple, le questionnaire de présence de Kim et Biocca (1997) se base sur le SUS ainsi que sur un questionnaire de présence de Barfield et Weghorst (1993). L'IPQ, quant à lui, a été construit sur le SUS et le PQ. Un des intérêts particuliers de l'ITC-SOPI réside dans le fait que sa structure permet des comparaisons intermédia.

Tout comme les mesures objectives de présence, les mesures subjectives souffrent de certaines faiblesses. Celles-ci incluent des problèmes de fiabilité (voir Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000) ainsi que d'interprétation (p. ex., l'usager peut avoir de la difficulté à quantifier, de manière constante, le concept de « se sentir là »; Thornson, Goldiez, & Le, 2009). De plus, ce type de mesure subjective exige une certaine capacité à l'introspection (Sas & O'Hare, 2003). Pour ce qui est spécifiquement des mesures verbales à un item prises durant immersion (p. ex., « Sur une échelle de 0 à 100, à quel point avez-vous l'impression d'être ici dans la cuisine? »), elles peuvent être instables et sujettes à l'influence d'expériences antérieures (Freeman, Avons, Pearson, & IJsselsteijn, 1999). Il a également été suggéré que le simple fait de demander une quantification du degré de présence peut influer sur le sentiment de présence, voir même le produire (Slater, 2004). Les mesures post-immersion, quant à elles, peuvent mesurer des rationalisations post-hoc au lieu de mesurer l'expérience en tant que telle (Freeman, Avons, Pearson, & IJsselsteijn, 1999; Slater, 1999, 2004; Usoh, Catena, Arman, & Slater, 2000). Certains auteurs ont même trouvé qu'un questionnaire typique ne peut pas distinguer entre la présence dans un EV et la réalité physique (Usoh, Catena, Arman, & Slater, 2000). Pris dans leur ensemble, ces faiblesses suggèrent que l'expérience rapportée per- ou post-immersion pourrait ne pas correspondre tout à fait à l'expérience vécue (p. ex., Freeman, Avons, Pearson, & IJsselsteijn, 1999; Slater, 1999, 2004; Usoh, Catena, Arman, & Slater, 2000).

Sommaire sur les mesures de présence. Compte tenu de leurs forces et faiblesses respectives, l'utilisation de mesures per-et post-immersion semblerait appropriée pour quantifier le sentiment de présence. Dû à l'interruption de présence qu'une mesure prise durant l'immersion pourrait causer, cette mesure devrait se limiter à un item. Pour ce qui est d'une mesure post-immersion, l'ITC-SOPI se démarque par ses capacités d'être utilisé dans des comparaisons intermédia, ainsi que de rendre compte de la présence personnelle, l'engagement, la validité écologique et les effets négatifs de l'EV.

Les Variables Influençant le Sentiment de Présence

Compte tenu de l'importance du sentiment de présence dans l'expérience de la RV, il semble pertinent de déterminer les variables qui pourraient l'influencer. Ces dernières sont le sujet de nombreuses recherches et elles ont été catégorisées de différentes manières. Sheridan (1992) les regroupe en trois catégories : l'ampleur de l'information sensorielle, le contrôle des capteurs (« *sensors* »), et le degré de l'habileté à modifier l'environnement. Steuer (1995) les catégorise en degré de vivacité (« *vividness* »), degré d'interactivité et caractéristiques individuelles de l'usager. Quant à Lombard et Ditton (1997), ils les catégorisent en forme de présentation, contenu de l'information et caractéristiques individuelles de l'usager. Finalement, Witmer et Singer (1998) regroupent les variables en quatre facteurs : le contrôle, la richesse des stimuli, les distractions externes à l'EV, et le réalisme (visuel et social). Dans le présent document, les variables qui pouvant influer sur le degré de présence ont été catégorisées en facteurs individuels et facteurs environnementaux.

Les facteurs individuels. Certaines caractéristiques de caractère (« *trait* ») ou d'état (« *state* »; Jerome & Jordan, 2007) de l'usager peuvent jouer un rôle dans le degré du sentiment de présence; ainsi, un même EV peut évoquer des degrés de présence différents selon l'usager (Steuer, 1995). Dans cette catégorie de variables, on retrouve la sensibilité d'un individu au cybermalaise (phénomène semblable au mal des transports). En effet, durant une immersion en RV, un utilisateur peut être atteint d'un cybermalaise, réduisant ainsi le sentiment de présence (Kennedy, Stanney, & Dunlap, 2000). D'autres facteurs individuels qui peuvent avoir un impact sur le sentiment de présence dans un EV incluent l'âge (Bangay & Preston, 1998), l'empathie (Nicovich, Boller, & Cornwell, 2005), l'absorption (Lombard & Ditton, 1997), l'imagination créative (Heeter, 1992; Lauria, 1997), les habiletés cognitives (Sacau, Laarni, & Hartmann, 2008), la volonté d'être transporté dans un EV et « d'accepter » l'EV comme réel (Laurel, 1993; Slater & Usoh, 1993; Steuer, 1995), l'anxiété (Renaud, Bouchard, & Proulx, 2002; Robillard, Bouchard, Fournier & Renaud, 2003) et la peur (Schuemie et al., 2000).

Les facteurs environnementaux.

Le degré d'interactivité avec l'EV. Les variables environnementales peuvent être réparties en trois sous-catégories, dont la première aborde le degré d'interactivité possible avec l'EV. En effet, Welch et collègues (1996) rapportent un effet positif de l'interaction sur le sentiment de présence. Steuer (1995) définit l'interactivité comme la mesure dans laquelle l'usager participe à modifier, en temps réel, la forme et le contenu de l'EV. La possibilité d'être un acteur d'un point de vue égocentrique (Slater, Linakis, Usoh, & Kooper, 1996), c'est-à-dire de pouvoir interagir avec l'EV (au lieu de simplement l'observer), a des retombées positives sur le sentiment de présence (Welch, Blackmon, Liu, Mellers, & Stark, 1996). Sheridan (1992) suggère que les possibilités de changer son propre point de vue dans l'environnement et de modifier les caractéristiques physiques de l'environnement contribuent au sentiment de présence. En effet, il semble que l'habileté d'un système de suivi de position (« *head-tracking* ») à ajuster la scène visuelle selon les mouvements de l'utilisateur (Hendrix & Barfield, 1996a) ainsi qu'un délai réduit entre le mouvement de tête et la mise à jour de l'image (Meehan, Razzaque, Whitton, & Brooks Jr, 2003) soient associés à un sentiment de présence plus élevé. Inversement, un retard de la rétroaction de l'EV sur les actions de l'usager a un effet négatif sur le sentiment de présence (Welch, Blackmon, Liu, Mellers, & Stark, 1996). De plus, le degré de contrôle de l'utilisateur sur ses actions (Witmer & Singer, 1994), la possibilité de voir son « propre » corps durant l'interaction (même s'il ne s'agit que d'une représentation virtuelle; Slater & Usoh, 1994) et la facilité de l'interaction avec l'environnement (Billinghurst & Weghorst, 1995) semblent influer sur le sentiment de présence. Le degré de réciprocité d'action entre l'utilisateur et l'environnement virtuel semble également jouer un rôle dans le degré du sentiment de présence. En effet, des facteurs sociaux, tels que la reconnaissance de la présence de l'utilisateur par d'autres individus dans l'environnement virtuel, semblent également influer sur le sentiment de présence (Heeter, 1992). Il importe de noter que, malgré un sentiment de présence initialement élevé, les comportements socialement ou physiquement inhabituels d'un personnage virtuel peuvent faire redescendre le degré de sentiment de présence (Garau et al, 2008).

La perception de stimuli non concordants à l'expérience virtuelle. Le degré du sentiment de présence semble, en partie, déterminé par l'habileté de l'environnement virtuel à isoler l'utilisateur des stimuli de l'environnement non synthétique. En effet, il implique des processus ascendants et descendants (Ijsselsteijn & Riva, 2003), et afin d'accéder au sentiment de présence en EV, les variables environnementales doivent être capables, entre autres, de faire taire les processus ascendants générés par des stimuli non synthétiques et non concordants avec l'EV. Il n'est donc pas surprenant que l'ergonomie du système joue un rôle dans le sentiment de présence, et que le confort du système peut influer sur le sentiment de présence (Billinghurst & Weghorst, 1995). En effet, un équipement qui incommode l'utilisateur durant l'immersion risque de rappeler à ce dernier que son expérience se base sur une illusion, et dans ce cas, sa capacité de se sentir présent dans l'EV risque de se détériorer (Slater & Usoh, 1993).

Les qualités de l'environnement virtuel. Cependant, il ne suffit pas d'isoler les processus ascendants des stimuli non concordants avec l'EV, il faut également nourrir les processus ascendants de stimuli capables d'activer des processus descendants concordants avec l'EV. Cette troisième sous-catégorie de variables environnementales aborde donc la qualité des stimuli de l'environnement virtuel. Barfield et collègues (1998), Welch et collègues (1996) ainsi que Waterworth et Waterworth (2003) suggèrent qu'il existe une relation positive entre le réalisme des images et le sentiment de présence, mais que cette relation est limitée. Alors que Billinghurst et Weghorst (1995) rapportent que la qualité de l'écran peut prédire le sentiment de présence, il semble également qu'une plus haute fréquence des images (un minimum d'environ 15 Hz semble nécessaire; Barfield, Baird, & Bjorneseth, 1998; Barfield & Hendrix, 1995), un champ de vision plus large (Hendrix & Barfield, 1996a; Lin, Duh, Abi-Rached, Parker, & Furness, 2002; Prothero & Hoffman, 1995), ainsi qu'un environnement stéréoscopique (Freeman, Avons, Meddis, Pearson & IJsselsteijn, 2000; Hendrix & Barfield, 1996a) sont associés à un sentiment de présence plus élevé. Selon Snow et Williges (1998), la résolution visuelle ainsi que la texture des images représentent des paramètres significatifs, et ils seraient tout aussi importants que d'autres facteurs tels que le champ de vision et le suivi de position. De plus, ils suggèrent que le champ de vision, le son, et le suivi de position ont presque trois fois plus d'influence sur le sentiment de présence que la résolution de l'image, la texture de la scène visuelle (« *texture mapping* »), la stéréoscopie, et le taux de rafraîchissement de la scène visuel (Snow & Williges, 1998).

Les résultats ci-dessus suggèrent que, généralement, les stimuli virtuels s'approchant de ceux du monde non synthétique ont un effet positif sur le sentiment de présence. Steuer (1995) suggère qu'en augmentant le nombre de sens stimulés, le sentiment de présence pourrait être augmenté. Effectivement, il a été rapporté que le son (Dinh, Walker, Song, Kobayashi, & Hodges, 1999; Gilkey & Weisenberger, 1995), le son spatialisé (Hendrix & Barfield, 1996a,b), et l'augmentation tactile (Dinh, Walker, Song, Kobayashi, & Hodges, 1999; Hendrix & Barfield, 1996a; Hoffman et al., 1996; Meehan, Insko, Whitton, & Brooks, 2002) peuvent contribuer au sentiment de présence. De plus, la mobilisation du corps (Slater & Steed, 2000; Slater, Steed, McCarthy, & Maringelli, 1998) ainsi que la réduction de la dissociation entre la proprioception et les sens semblent avoir une influence positive sur le sentiment de présence. Par exemple, un usager qui marche sur place alors qu'il se déplace dans l'EV en activant une manette de jeu ressent un degré de présence plus élevé que celui qui se déplace dans l'EV simplement en activant une manette de jeu (Slater, Usoh, & Steed, 1995; Usoh et al, 1999).

En somme, le sentiment de présence peut être influencé par deux catégories de variables : (a) des facteurs individuels liés aux caractéristiques de personnalité (« trait ») et aux états situationnels (« state ») de l'usager et, (b) des facteurs environnementaux liés aux caractéristiques de l'équipement de RV ainsi qu'aux qualités de l'EV; parmi ces dernières on trouve le nombre de sens stimulés. Sur cette base, on peut avancer l'hypothèse que la stimulation du sens de l'olfaction pourrait avoir un effet sur le sentiment de présence d'un usager.

L'Intérêt d'Intégrer des Stimuli Olfactifs en Réalité Virtuelle

L'olfaction. L'olfaction se définit comme la sensation d'odeurs résultant de la détection de substances odorifiques aérolisées dans l'environnement (Simpson & Sweazy, 2006). Il importe de distinguer entre les termes « odeur » et « odorant. » Alors qu'un odorant (ou stimulus olfactif) correspond à une entité physicochimique de molécules dans l'environnement (Hudson & Distel, 2003), une odeur correspond à la perception créée par le système nerveux du sujet, et ceci, en réaction au contact entre les récepteurs olfactifs et le patron moléculaire de l'odorant (Hudson & Distel, 2003). Une odeur résulte d'un percept subjectif produit par la combinaison d'un stimulus olfactif et d'un contexte; elle est modulée par le système nerveux (Hudson & Distel, 2003), sa signification s'acquiert probablement par le biais d'expériences individuelles (Hudson, 1999), son intensité perçue dépend d'une interprétation et d'une évaluation cognitive, et elle peut donc être modifiée par l'apprentissage (Stockhorst & Pietrowsky, 2004). La valeur hédonique, la familiarité et l'intensité sont les dimensions utilisées pour qualifier une odeur, mais elles ne sont pas totalement interindépendantes (Delplanque et al., 2008). De ces trois dimensions, la valeur hédonique (c'est-à-dire le degré d'agréabilité), aussi appelée la valence (Schiffman, 1974), est la plus saillante (Engen & McBurney, 1964; Harper, Land, Griffiths, & Bate-smith, 1966). La valeur hédonique n'est pas quantifiée selon un continuum d'agréabilité, mais selon deux qualificatifs opposés : l'agréabilité et la désagréabilité (Godinot, Sicard, & Dubois, 1995; Schiffman, 1974).

Il semble paradoxal que le système olfactif soit la façon la plus ancienne de transmettre de l'information sensorielle au cerveau, et qu'elle soit également la moins bien comprise (Ratey, 2001). En effet, dans le domaine de la recherche comportementale en général, l'olfaction n'a pas évoqué autant d'intérêt que la vision ou l'audition (Chu & Downes, 2000). Pourtant, le sens de l'olfaction joue un rôle significatif dans la vie de tous les jours (Drummond, Douglas, & Olver, 2007) et sa perte, ou son altération ont des chances considérables d'influer, d'une manière négative, sur la qualité de vie (Pollatos et al., 2007; Simpson & Sweazy, 2006) et l'expérience émotionnelle (Pollatos et al., 2007) de l'individu touché. D'ailleurs, de nombreuses études suggèrent que les stimuli olfactifs peuvent exercer une influence sur divers processus cognitifs. Ils semblent pouvoir diminuer (Mellier, Bézard, & Caston, 1997; Rattaz, Goubet, & Bullinger, 2001) et augmenter (Villemure, Wassimi, Bennett, Shir, & Bushnell, 2006) la perception d'une douleur; ce phénomène est peut-être modéré par le biais de l'humeur (Villemure, Wassimi, Bennett, Shir, & Bushnell, 2006). Des odeurs stimulantes peuvent augmenter la vigilance (Goel & Lao, 2006; Weber & Heuberger, 2008). De plus, une odeur concordant, de manière sémantique (Platek, Thomson, & Gallup, 2004) ou hédonique (Ehrlichman & Halpern, 1988), avec une image ou un mot, semble faciliter la détection de cette image, ou la production de ce mot.

Le relativement faible intérêt pour l'olfaction s'applique également au domaine de la RV et divers facteurs pourraient influencer cette sous-utilisation de stimuli olfactifs. Premièrement, dû à leurs actions souvent subliminales, leur importance au jour le jour reste souvent méconnue (Albrecht & Wiesmann, 2006). Deuxièmement, dû à leur composition complexe et leur caractère transitif, leur utilisation s'avère plus complexe que celles de stimuli visuels ou acoustiques (Stockhorst & Pietrowsky, 2004). Finalement, l'interprétation fortement subjective d'une odeur rend une généralisation particulièrement difficile.

Les stimuli olfactifs en RV. En 1962, avec des moyens bien plus modestes que ceux sur le marché aujourd'hui, le Sensorama de Heilig (1962), un système que certains considèrent comme l'ancêtre de la RV (Ghinea & Ademoye, 2011), exposait un usager à des stimuli de mouvement, de vibrations, de son, de vent et d'odorants. Le Sensorama permettait à l'usager de vivre une expérience multisensorielle lors d'un tour virtuel de motocyclette à travers des rues de Brooklyn. Cinquante ans plus tard et malgré une croissance exponentielle des capacités technologiques, les stimuli visuels et auditifs dominent largement la RV. Peu de systèmes de RV exposent les usagers à des stimuli olfactifs et cela, malgré le fait que les récepteurs olfactifs fournissent une source d'information riche à l'humain (Barfield & Danas, 1996).

Depuis le Sensorama, les stimuli olfactifs ont été utilisés dans peu d'applications et certains auteurs (p. ex., Biocca & Delaney, 1995) lient cette absence à la difficulté de produire et de maîtriser les odorants de manière précise. Dans le domaine du divertissement, ils ont été utilisés dans le but d'augmenter le réalisme de l'expérience. Par exemple, le « *Kyongju VR Theatre* », un cinéma interactif, a été construit pour l'Exposition des Cultures du Monde de Kyongju (2000). Lors d'un voyage virtuel de 15 minutes, durant lequel les spectateurs peuvent influer sur le trajet dans l'environnement virtuel, les usagers sont exposés à un de cinq odorants correspondant aux diverses scènes visuelles (ChangHoon et al., 2002). Quelques années plus tard, le projet DIODE (Papin et al, 2003) permettait une promenade virtuelle à travers la Place Vendôme de Paris. Dans cette dernière se trouvaient un sapin de Noël, une rose ainsi qu’un oranger. Lorsque l’usager entrait dans la sphère olfactive d’un de ces objets, l’odorant approprié était diffusé, accompagné d’une représentation visuelle des particules odorantes.

Mais l'utilité des stimuli olfactifs en RV va bien au-delà des applications ludiques en apportant une information critique à l'exécution de certaines tâches; c'est le cas de l’« *Advanced*

Virtual Environment Real-Time Fire Trainer » (AVERT) de Cater (1994). Ce système d'entraînement combine des stimuli visuels, auditifs, olfactifs et de chaleur infrarouge radiante pour immerger l'usager dans un environnement d'incendie virtuel. Compte tenu du danger additionnel que représentent certaines matières dangereuses durant un incendie, cette plateforme a pour but de familiariser des pompiers aux diverses odeurs leurs étant associées. Par le biais du masque à oxygène, l'usager peut être exposé à sept odeurs (p. ex., du sulfure, du bois qui brule, de la graisse et du caoutchouc, de l'huile, du gaz d'échappement).

Dans le but de rendre la formation en RV plus semblable aux interventions réelles, l'intégration de stimuli olfactifs fait également son chemin dans le domaine de la médecine. En effet, Spencer (2006) rappelle l'importance accordée aux odeurs pour certains diagnostics (p. ex., choc diabétique, défaillance rénale, empoisonnement) et durant certaines chirurgies (p. ex., rupture de la vésicule biliaire, infection de la bile). Alors que Spencer (2006) recommande leur intégration dans certains scénarios de formation médicale, Krueger (1995) va plus loin en suggérant que pour la formation en chirurgie, un système de RV reste incomplet s'il n'intègre pas de stimuli olfactifs.

Les odorants ont également le potentiel d'être utilisés dans le cadre d'applications de psychologie clinique en RV (p. ex. la modification des comportements face à certaines drogues). En effet, des indices multisensoriels (se trouver dans un bar virtuel, entendre le bruit des verres et sentir l'odeur de boissons alcoolisées) peuvent déclencher les réactions physiologiques et psychologiques associées à la présence de ces drogues (Bordnick et al., 2008). Une fois le besoin de consommation déclenché, le thérapeute peut enseigner des techniques cognitives et comportementales permettant au patient de résister à l'envie de consommer. Dans un autre domaine clinique, l'inclusion de stimuli olfactifs a également trouvé son utilité dans le traitement de l'état de stress post-traumatique. Par exemple, dans l'EV « *Virtual Iraq* », des odeurs d'épices du Moyen-Orient, de caoutchouc incendié et de cordite sont utilisées afin de faciliter l'accès à - et donc le traitement de - souvenirs traumatiques (Cukor, Spitalnick, Difede, Rizzo, & Rothbaum, 2009).

En somme, dans le monde non synthétique, les stimuli olfactifs peuvent agir sur de nombreux processus mentaux et leur importance a été reconnue par divers auteurs. Il est donc tout à fait raisonnable d'anticiper que, tel que l'on fait les concepteurs des applications décrites ci-dessus, leur intégration en RV devrait avoir un effet sur l'expérience de l'usager. Mais qu'en est-il d'une vérification empirique de la valeur ajoutée des stimuli olfactifs en RV? Comment quantifier cette valeur ajoutée? Par le degré de réalisme, le degré de réalité, le degré de présence, ou par un autre concept? Compte tenu de son importance avérée en RV, le sentiment de présence semble être un indicateur de choix.

Les Stimuli Olfactifs et le Sentiment de Présence

Plus précisément, si on adhère à l'idée que l'augmentation du nombre de sens stimulés peut contribuer à un sentiment de présence plus élevé, alors l'ajout d'un stimulus olfactif devrait avoir un effet positif sur le sentiment de présence. Cette hypothèse a été avancée par divers auteurs (p. ex., Cater, 1992; Zybura & Eskeland, 1999; Lombard & Ditton, 1997; Washburn, Jones, Vijaya Satya, Bowers & Cortes, 2003; Chen, 2006). Barfield et Danas (1996) formulent cette hypothèse quelque peu différemment : ils suggèrent que l'absence d'une odeur ajoutée constitue une lacune en RV. En effet, alors qu'un EV se caractérise par des stimuli visuels et auditifs qui lui sont propres, l'absence de l'ajout de stimuli olfactifs ne permet pas une distinction olfactive entre les mondes non synthétique et virtuel. Du point de vue de l'olfaction, le « départ » de l'usager de la pièce réelle et son « arrivée » au lieu virtuel (Kim & Biocca, 1997) ne sont pas facilités. En somme, Barfield et Danas (1996) ne suggèrent pas que l'exposition à des odorants en RV améliore l'expérience de l'EV, mais que leur absence lui nuit. Cependant, malgré cet intérêt théorique pour la relation entre les stimuli olfactifs et le sentiment de présence, seulement deux articles semblent avoir fourni des données empiriques au sujet du lien entre un stimulus olfactif et le sentiment de présence en RV, et un troisième a examiné le lien entre un stimulus olfactif et le degré d'immersion.

Le premier de ces articles (Dinh et al., 1999) visait à établir si le degré des détails visuels, jumelés avec les présences ou absences de stimuli tactiles, de stimuli auditifs et de stimuli olfactifs pouvait influer sur : (a) le souvenir de l'expérience virtuel, et (b) le sentiment de présence. Le protocole consistait à visiter les cinq pièces d'un bureau. Dans la salle d'accueil, le participant pouvait être, ou ne pas être, exposé à une odeur de café (une cafetière y était visible dans la pièce). Le stimulus olfactif était diffusé par le biais d'un masque à oxygène porté par le participant. Les résultats de cette étude inter-groupes de 322 participants, dans 16 conditions, suggèrent que l'exposition à un stimulus olfactif a un effet significatif sur le souvenir de l'expérience virtuelle. Cependant, à propos de l'effet d'un stimulus olfactif sur le sentiment de présence, les résultats n'ont révélé que des tendances non significatives. Malgré ces résultats suggérant qu'un stimulus olfactif n'a pas d'effet sur le sentiment de présence, quelques faiblesses méthodologiques laissent planer un doute. Premièrement, en informant les participants du but de l'expérimentation et des variables indépendantes, les chercheurs peuvent avoir introduit un biais pour certains participants (un participant pensant qu'une odeur devrait augmenter le sentiment de présence pourrait, consciemment ou pas, ajuster son score en conséquence). Ensuite, l'ambition de vérifier quatre modalités en une seule expérience a nui à la possibilité de varier certaines dimensions du stimulus olfactif. En effet, l'odeur de café est une odeur généralement considérée comme agréable et, dans ce scénario, elle est également concordante à l'EV (en viendrait-on aux mêmes résultats si l'odeur était désagréable ou discordante?). Une autre réserve méthodologique concerne l'absence de moyen pour vérifier, et donc de contrôler, certaines différences potentielles entre les groupes (degré de base de présence, degré de sensibilité à un stimulus olfactif, propension à l'immersion, et degré de cybermalaise).

Le second de ces articles (Serrano, Baños, & Botella, 2016) avait pour objectif principal de vérifier l'efficacité d'une procédure d'induction d'humeur à induire un état de relaxation. Parmi les objectifs secondaires, les auteures voulaient vérifier l'effet d'un stimulus olfactif sur le sentiment de présence. Selon le protocole, il s'agissait de visiter quatre pièces et les deux terrasses d'une maison. Dans chacune des pièces, le participant pouvait modifier certains des éléments de la pièce (p. ex., les posters, les couleurs et le matériel du plancher). Les résultats de cette étude inter-groupe de 136 participants, répartis de façon aléatoire dans quatre conditions (stimuli visuels et auditifs; stimuli visuels, auditifs et olfactif; stimuli visuels, auditifs et haptiques; stimuli visuels, auditifs, olfactif et haptiques), ont révélé que l'exposition à un stimulus olfactif n'était pas liée à une augmentation statistiquement significative du sentiment de présence. Cependant, certaines faiblesses méthodologiques pourraient avoir contribué à ce résultat. Premièrement, le stimulus olfactif (une odeur de lavande) était diffusé dans la salle d'immersion, sous le regard du participant, avant même l'immersion. D'un point de vue olfactif, il n'y avait donc pas de différence entre les mondes non synthétique et synthétique. Deuxièmement, on demandait au participant de coter son degré de présence global, c'est-à-dire, pour la totalité de l'expérience. Étant donné que les décors pouvaient varier d'un participant à l'autre, on ne peut exclure la possibilité que les différences de décors aient pu avoir des effets variables sur le sentiment de présence. Finalement, aucune différence inter-groupe (p. ex., degré de cybermalaise) concernant de potentielles co-variables du sentiment de présence n'a été vérifiée.

Une troisième étude n'aborde pas le lien entre stimuli olfactifs et présence, mais celui entre stimuli olfactifs et immersion. Cependant, compte tenu de la relation étroite entre ces deux concepts (et de la rareté des publications sur le sujet principal), il semble approprié que l'étude complétée par Jones et collègues (Jones, Bowers, Washburn, Cortes, & Satya, 2004) soit mentionnée ici. Durant cette expérience, trois groupes de participants étaient invités à jouer un jeu vidéo, soi-disant immersif. Alors que le groupe contrôle de ce projet n'était exposé à aucun odorant particulier, les groupes expérimentaux étaient exposés soit à une odeur concordante à la scène visuelle (odeur de brume marine lorsqu'au-dessus de l'océan et odeur de renfermé lorsqu'à l'intérieur d'un fort), soit à une odeur discordante à la scène visuelle (odeur de sirop d'érable tout au long du jeu). Les résultats de cette étude suggèrent que les trois groupes ont coté l'EV de manière significativement différente, mais que l'exposition à l'odorant, qu'il soit concordant ou discordant, n'avait pas d'effet significatif sur le degré d'immersion. Cependant, quelques faiblesses méthodologiques laissent également douter des résultats de cette étude. Premièrement, il n'est pas clair quelles instructions ont été données aux participants (p.ex., étaient-ils au courant du but exact de l'étude?). Ensuite, un écran de 5' par 5' est peu immersif et, par définition, l'absence d'une vision en 3D disqualifie cet environnement d'être considéré comme de la RV. Plus important encore, le questionnaire utilisé pour mesurer la variable dépendante, l'« *augmented immersion questionnaire* », n'est ni connu, ni inclus dans l'article; il est donc difficile de vérifier ce qui est vraiment mesuré. Finalement, tout comme les deux études précédentes, la faiblesse majeure réside dans l'absence de mesures de base et de certaines co-variables potentielles du sentiment de présence.

Malgré ces résultats suggérant qu'un stimulus olfactif n'a pas d'effet sur le sentiment de présence, quelques faiblesses méthodologiques laissent planer un doute. Premièrement, en informant les participants du but de l'expérimentation et des variables indépendantes, les chercheurs risquent d'avoir introduit un biais dans la variable dépendante. Ensuite, l'ambition de vérifier quatre modalités en une seule expérience a nui à la possibilité de varier certaines dimensions du stimulus olfactif. En effet, l'odeur de café est une odeur généralement considérée comme agréable et, dans ce scénario, elle est également concordante à l'EV (en viendrait-on aux mêmes résultats si l'odeur était désagréable ou discordante?). Cependant, la plus grande réserve méthodologique concerne l'absence de moyen pour vérifier, et donc de contrôler, certaines différences potentielles entre les groupes (degré de base de présence, degré de sensibilité à un stimulus olfactif, propension à l'immersion, et degré de cybermalaise).

Hypothèse de Recherche

En somme, les applications de RV peuvent servir de nombreuses applications utiles et le sentiment de présence joue un rôle central dans l'expérience de l'EV. Il semble donc important de connaître, et de pouvoir influer sur, les variables qui l'affectent. Parmi ces dernières, les facteurs individuels sont difficiles à influencer, mais on pourrait affecter le sentiment de présence en manipulant certains facteurs environnementaux. Alors que certains chercheurs avancent que l'ajout de stimuli olfactifs devrait avoir un effet sur le sentiment de présence, très peu de publications abordent directement le sujet et, qui plus est, les méthodologies de ces études ne sont pas entièrement convaincantes. Le but de cette recherche était donc de jeter plus de lumière sur la relation entre les stimuli olfactifs et le sentiment de présence.

L'hypothèse générale de ce projet stipule que l'exposition à un stimulus olfactif peut augmenter le sentiment de présence en RV. Cette hypothèse a été vérifiée à l'aide de trois études utilisant des EV quelque peu différents. L'hypothèse de la première étude (article 2) était que, dans un EV privé d'éléments visuels faisant un lien explicite avec une odeur, l'exposition à une odeur, qu'elle soit agréable ou désagréable, entraînerait une augmentation du sentiment de présence. L'hypothèse de la seconde étude (article 3) était que, dans un EV dont certains éléments visuels font un lien avec une odeur désagréable, les participants exposés à une telle odeur ressentiraient un plus haut degré de présence que ceux exposés à l'air ambiant. Finalement, l'hypothèse de la troisième étude (article 4) était que, dans un EV dont certains éléments visuels font un lien avec une odeur agréable, les participants exposés à une telle odeur ressentiraient un plus haut degré de présence que ceux exposés à l'air ambiant. L'intérêt de ce projet était de contribuer aux connaissances sur l'utilité d'intégrer des stimuli olfactifs dans le but d'enrichir l'expérience humaine en RV. En guise d'avant-propos aux trois études, l'article 1 passe en revue le sens de l'olfaction, ses caractéristiques et son éventuelle intégration dans diverses applications en RV.

Article 1

The Sense of Olfaction:

Its Characteristics

and

Its Possible Applications in Virtual Environments (VE).

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Abstract

Virtual environments (VE) aim to reproduce life-like experiences, but despite indications that the olfactory sense plays a significant role in everyday life, the integration of olfactory stimuli in VEs is rare. The aim of this paper is to review the literature on olfaction and its potential applications in Virtual Reality (VR). Indications supporting the integration of odorants in VR include the privileged connections between the olfactory system and the brain regions involved in the processing of virtual stimuli used in clinical applications, as well as the interaction between odours, the other senses, and various psychological processes. Presently, smells are mostly integrated in VR applications for post-traumatic stress disorder and drug addiction, but further uses of odorants in VEs could include pain distraction, various training scenarios (e.g., emergency response, relaxation, etc.), and investigations of multi-sensory integration.

Keywords: olfaction, smell, odour, virtual environment, virtual reality

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"Of all the ways of getting sensory information to the brain, the olfactory system is the most ancient and perhaps the least understood" (Ratey, 2001, p. 62). The sense of smell is believed to have been a major catalyst in the evolution of the primitive brain, and it is suspected that the entire limbic system actually evolved from its original function of interpreting odorants and emitting pheromones (Ratey, 2001). Its significance for animals is readily recognized (Ache & Young, 2005): it plays a role in their search for food, navigation and orientation, reproductive behaviour, and social organisation (Albrecht & Wiesmann, 2006). Although many of these aspects also apply to humans (Albrecht & Wiesmann, 2006), many tend to consider olfaction of minor importance (Shepherd, 2006).

The relatively minor interest in the olfactory sense is also reflected in the field of virtual reality (VR), and various factors may contribute to the underutilisation of olfactory stimuli in virtual environments (VE). According to Sadowski (1999), these factors include the perception that incorporating olfaction stimuli would neither enhance the virtual experience, nor be useful in concrete applications. Most importantly, the primary obstacle to a generalised integration of olfactory stimuli in VEs may be the difficulty in dispensing and controlling the odorants in the environment (Sadowski, 1999).

To date, relaxation techniques (e.g., Kawai & Noro, 1996), post-traumatic stress disorder (PTSD) treatment (e.g., Gerardi, Rothbaum, Ressler, Heekin, & Rizzo, 2008), and drug addiction research (e.g., Bordnick et al., 2008; Ryan, Kreiner, Chapman, & Stark-Wroblewski, 2009) belong to the rare applications integrating olfactory cues in clinically pertinent VR scenarios. More specifically, Kawai and Noro (1996) co-ordinated olfactory cues with the content of stereoscopic 3-D images (e.g., fragrance of forest with 3-D images of a green forest) in order to experiment the relaxation effects of such combinations. The results of this experiment suggest that such associations can lead to a psychological effect (as measured in three psychological factors: depressive mood, anxious mood, as well as tension and excitement) that differs according to the type of fragrance (forest, marine, or lavender). In the field of PTSD treatment in VR, Gerardi and colleagues' (2008) protocol calls for exposure to visual, auditory, tactile (i.e., vibration), and olfactory stimuli (burning rubber, diesel fuel, weapons fire and spices). During treatment, the patient is exposed to multi-sensory combat zone stimuli while driving a Humvee in either urban or non-urban "Iraq-like" scenes; the intensity of these stimuli increases gradually across sessions. The results of this brief, single case, VR exposure treatment included clinically and statistically significant changes in scores on the Clinician Administered PTSD Scale (Blake et al., 1990) and the PTSD Symptom Scale Self-Report (Foa, Riggs, Dancu, & Rothbaum, 1993), thereby suggesting preliminary promise for this type of intervention (Gerardi et al., 2008). In the field of substance abuse and addictions, Bordnick and colleagues' (2008) VR alcohol cue reactivity assessment system incorporates visual, auditory and olfactory stimuli; these included the scents of vanilla, pizza, coffee, the preferred drink of participant (whiskey, beer, brandy, tequila, gin, scotch, red wine, white wine), beer, cigarette smoke, and pine trees. During trials involving non-treatment seeking individuals with alcohol use disorders, the exposure of the subjects to multi-sensory alcohol related cues generated higher subjective alcohol cravings than when these cues were absent. Furthermore, the multi-modal VE appears to be associated with high levels of presence in VR (Bordnick et al., 2008). In an interesting variation on the previous experience, Ryan et al. (2009) found that, when exposed to multi-sensory alcohol related cues, binge drinking college students report significantly higher cravings for, and thoughts of, alcohol than non binge drinkers.

Yet, considering that the sense of smell plays a significant role in everyday human life (Drummond, Douglas, & Olver, 2007), and that its loss or impairment has significant chances of adversely affecting an individual's quality of living (Pollatos et al., 2007; Simpson & Sweazy, 2006) and emotional experience (Pollatos et al., 2007), it would seem that the successful integration of olfactory stimuli in VEs should be pursued more actively. Thus, the purpose of this paper is to provide VR researchers an overview of the olfactory system, and its involvement in psychological reactions, in the hope that this information may contribute to an increased use of olfactory cues in VR clinical applications. To this end, the information is structured into six sections, the first of which briefly addresses the neuroanatomy of the olfactory system. The next two sections cover the capabilities of the olfactory sense, and the characteristics of odours. Next, the potential interactions involving the olfactory sense are covered; while the fourth section presents various factors that influence olfactory processing, the fifth section presents some of the influences of odours on physiological state, perception and mental processes. Lastly, the present status of the research involving the sense of olfaction, and the use of olfactory stimuli in VEs will be discussed; this discussion will introduce some of the present, and some of the potential, applications of exposure to olfactory stimuli in VEs.

Neuroanatomy of the olfactory system

Olfaction is the "sensation of odours that results from the detection of odorous substances aerosolized in the environment" (Simpson & Sweazy, 2006, p. 367), and thus, it is categorised as a chemical sense (as is the sense of taste). In addressing olfaction, it is important to distinguish between the terms “odour” and “odorant” (e.g., Hudson, 2000; Hudson & Distel, 2002a,b). While an odorant (or olfactory stimulus) is a physicochemical entity of molecules in the environment (Hudson & Distel, 2003), an odour is the percept created by a subject’s nervous system, in reaction to the contact between the olfactory receptors and the molecule patterns of the odorant (Hudson & Distel, 2003).

An odorant commences its transformation into an odour either from the outside (orthonasal) or from the inside (retronasal) of the subject’s body. Whereas orthonasal stimulation results from sniffing the ambient air, retronasal stimulation results when the odorants of ingested food travel up from the back of the oral cavity and through the nasopharynx into the nasal cavity (Shepherd, 2006). In either case, the odorant ends up in the olfactory mucosa, itself located in the superior and posterior part of the nasal cavity (Mackay-Sim & Royet, 2006). There, the odorant, which must be hydrophilic or lipophilic in order to dissolve in the mucus (Stockhorst & Pietrowsky, 2004), comes into contact with the olfactory receptors of the olfactory epithelium (Ratey, 2001). The axons of the sensory neurons fasciculate to form the fila olfactoria (Mackay-Sim & Royet, 2006), which traverses the skull base through the cribriform plate, to then, enter the olfactory bulb. The left and right olfactory bulbs are interconnected via the anterior commissure (Mackay-Sim & Royet, 2006), and axons leave the olfactory bulb via the olfactory tract, to then project onto a group of structures collectively referred to as the primary olfactory cortex (Mackay-Sim & Royet, 2006). These structures include the amygdala which seems to play critical roles in odour processing (Jones-Gotman & Zatorre, 1993; Zald & Pardo, 2000), conditioned fear, attention (Bremner et al., 1999), as well as aversive and negative emotional states (Hamann & Mao, 2002). There exist important differences in neuroanatomical connections between the olfactory sense and other senses; the various connections of the olfactory system are illustrated at Fig.1. While other senses go through a series of cortical relays before reaching the limbic system, the olfactory bulb projects uncrossed (Ratey, 2001), and without being mediated by the thalamus (Simpson & Sweazy, 2006), onto the amygdala (there seems, however, to exist an additional indirect and less prominent link between the primary olfactory cortex and the secondary olfactory area via the thalamus; Djordjevic & Jones-Gotman, 2006). In addition, the connection to the orbitofrontal cortex provides olfaction with the "fastest route between perception and action" (Malaspina et al., 2006, p. 222).

In summary, an odour is the result of complex interactions between the molecular pattern of an odorant, the olfactory receptors, the olfactory bulb, the primary olfactory cortex and the secondary olfactory area. Most importantly, when compared to the other senses, the sense of olfaction enjoys a more direct, thus faster and less filtered, uncrossed connection with the amygdala. It is this privileged relation with the limbic system, as well as that with the orbitofrontal cortex, that speak in favour of the use of olfactory cues in VR. Indeed, many of these brain regions are involved in the processing of virtual stimuli used in clinical applications, including anxiety disorders (Phillips, Drevets, Rauch, & Lane, 2003), addictions (Everitt & Robbins, 2005) and eating disorders (Beckman, Shi, Levine, & Billington, 2009).

Capabilities of the olfactory sense

Differentiable behaviour and physiological changes expressed by newborn in reaction to odorants suggest that, unlike the visual system, the olfactory system is remarkably mature at birth (e.g., Schaal, Marlier, & Soussignan, 1998, 2000). However, other than for "an aversion for decaying, putrid or bitter things" (Morean, 2007, p. 157), the only inborn olfactory preference seems to be that for the mother's amniotic fluid (Schaal, Marlier, & Soussignan, 1998). It seems that the right hemisphere is involved in the elaboration of odours (e.g., Zatorre, Jones-Gotman, Evans, & Meyer, 1992; Zucco & Tressoldi, 1989), and that they are acquired as a whole entity (Zucco, 2007). Unlike vision or hearing, olfaction needs to be activated (Köster, 2002), and its olfactory bulb produced "images" are subconscious (Shepherd, 2006); this later point is supported by the absence of a significant relay in the thalamus (Shepherd, 2006). Furthermore, it seems impossible for a subject to conjure up an olfactory image (Moeran, 2007); to this difference with the other senses, Zucco (2003) offers the explanation that, unlike olfactory representations, visual (and verbal) representations are conceptual, and thus, they can give rise to conscious representations. Alike the other sensory modalities, the olfactory system habituates to a prevailing stimulus (Morean, 2007). This phenomenon is observable through a rapid decline in the pyriform cortex activation during constant exposure to a particular olfactory stimulus (Poellinger et al., 2001; Sobel et al., 2000).

In humans, the development of different cognitive processes for socialisation seems to have led to loss of function mutations in the olfactory receptor genes (Rouquier, Blancher, & Giorgi, 2000), and the human's olfactory acuity is inferior to that of most animal species (Malaspina et al., 2006). A person's ability to localize the source of an odorant - based on olfaction alone - is relatively poor (Kobal, Van Toller, & Hummel, 1989), and humans are anomic to certain odorants (Albrecht & Wiesmann, 2006). Nevertheless, an individual can detect up to 10,000 odorants (Albrecht & Wiesmann, 2006) with less than 10,000 receptors (Ratey, 2001). Hudson and Distel (2003) propose three ways the olfactory system is able to meet this challenge: the combination of wide spectrum receptors and neurons, the ability to learn, and the ability to adjust the sensitivity of the receptors according to the environment, the individual experience and the situation. However, despite its still impressive detection spectrum, the human is only able to discriminate between up to four separate components of an odorant (Laing &

Francis, 1989). Furthermore, unless it is exposed to certain odorants early in development, the olfactory system may never develop the ability to recognize them; conversely, one's olfactory sense can be improved through training (Ratey, 2001).

An odour incorporates a potentially great number of odorants into a single percept (about 800 in the case of coffee; Deibler, Acree, & Lavin, 1998). According to Albrecht and Wiesman (2006), each individual is equipped with a different set up of receptors, and they qualify one's olfactory world as individual as a fingerprint. It also appears that individual subjects encode one same odorant differently during consecutive presentations (Engen, 1983). In addition, it seems that the individuality of one's olfactory world is further defined by contextual contributions; indeed, Hudson and Distel (2003) suggest that individuals sharing the same sensory-chemical niche - the home, the neighbourhood, the city etc. - will respond to an olfactory stimulus in a more similar manner than those not sharing that same olfactory niche. In support to this suggestion, Stockhorst and Pietrowsky (2004) found that the perceived intensity of an olfactory stimulus depended on its concentration, as well as on the level of everyday experience with the odorant. Hence, an odour is a subjective percept produced by the combination of an olfactory stimulus and a context: it is modulated via the nervous system (Hudson & Distel, 2003), its meaning is probably acquired by individual experience (Hudson, 1999), its perceived intensity depends on interpretation and cognitive appraisal, and therefore, it can be modified through learning (Stockhorst & Pietrowsky, 2004).

In summary, the olfactory sense is remarkably mature at birth, it can detect up to 10,000 odorants, but the non-exposure to some odorants in early development may lead to an inability to detect them. Olfaction must be activated, habituates to prevailing stimulus, and it is impossible for a subject to conjure up an olfactory image. An odorant may be encoded differently during consecutive presentations, and its resulting odour is influenced by a variety of contextual contributions and personal experiences. Of particular interest to the integration of olfactory cues in VEs is the finding that the localisation of the source of an odorant, based on olfaction alone (i.e. without the support of the other senses), is relatively poor. For the purpose of integrating odours in a VE, the implication of this characteristic could be three-fold. For one, it allows, within certain limits, the use of a single remote source to release the olfactory cues (instead of using multiple sources and activating one, or the other, depending on the position and/or orientation of the user). The second implication may be that, in order to trigger the user's association between the odour and the intended virtual source of that odour, the visual (and potentially auditory as well as haptic) details need to "support" the intended odour (i.e., the odour of a lemon should be matched with a virtual object that looks and, if applicable, feels like a lemon). Lastly, the synchronisation between the user's virtual position and the timings of the releases of the olfactory cues need to controlled precisely (perhaps through a three dimensional model causing increasing odorant intensity as one approaches the intended virtual source).

Characteristics of odours

Dimensions of an odour

Hedonicity (the measure of pleasantness), familiarity and intensity are the dimensions mostly used to qualify an odour, and they are not totally independent of another (Delplanque et al., 2008). Hedonicity, also referred to as valence (Schiffman, 1974), is the most salient (Engen & McBurney, 1964; Harper, Land, Griffiths, & Bate-smith, 1966) of these dimensions. Hedonicity is not quantified via a continuum of pleasantness, but via two opposing clusters of pleasantness and unpleasantness (Godinot, Sicard, & Dubois, 1995; Schiffman, 1974), and the effect of a pleasant olfactory stimulus seems to be more persistent than that of an unpleasant one

(Weber & Heuberger, 2008). As proposed by the mere exposure effect (Cain & Johnson, 1978; Sulmont, Issanchou, & Köster, 2002), pleasantness and familiarity of odours seem to be positively correlated (e.g., Engen and Ross, 1973; Bensafi, et al., 2002). While Henion (1971) had suggested that, generally, an increase in intensity leads to decreased pleasantness, Moskowitz, Dravnieks, and Kiarman (1976) later suggested that, depending on the odorant used, the correlation could be positive, negative, complex or inexistent. It has also been suggested that the path for neutral or pleasant odours is slower, and cognitively more complex, than that for unpleasant odours (Rouby & Bensafi, 2002). As the former would be associated with higher order associations, it may also be more influenced by familiarity (e.g., Royet et al., 1999; Larsson, 2002). As proposed by Delplanque and colleagues (2008), the existence of two distinct paths for pleasant and unpleasant odours is in line with models suggesting the existence of different evaluative channels for the processing of positive and negative stimuli (e.g., Cacioppo, Garner, & Bernston, 1999; Sander, Koenig, Georgieff, Terra, & Franck, 2005). Furthermore, the existence of these two distinct paths is supported by neuroimaging (Fulbright et al., 1998; Zald & Pardo, 1997) and electrophysiological (Hummel & Kobal, 1992) results of cerebral activations during odour processing.

The dimensions qualifying an odour are hedonicity, familiarity and intensity; certain correlations seem to exist between these dimensions. In order to improve the VR experience, it may be useful to consider each of these three dimensions. For example, it is conceivable that the hedonicity of an odour could contribute to the determination of its intended virtual source (e.g., during immersion, the detection of a pleasant but non-specific odour, while the user is positioned equidistantly from an overflowing garbage can and a bouquet of flowers, is likely to favour an association between the pleasant odour and the flowers). Furthermore, the level of familiarity is likely to lead to a more rapid, and stronger, association with the cues presented via other modalities (e.g., the level of presence in a virtual kitchen may differ between users, depending on their familiarity with the type of food odorant use, which in turn, may be associated with cultural background). Finally, varying odorant intensities may be useful in cueing the user about the position, and rate of position change, relative to the intended virtual source of that odour.

Factors influencing olfactory processing

Gender

Herz (2004) reports that women are more sensitive to olfactory stimuli than men, and although the results are not unequivocal, consistent replications suggest that women outperform men in olfactory tests (e.g., Good & Kopala, 2006; Pause, Sojka, Krauel, Fehm-Wolfsdorf, & Ferstl, 1996). These differences appear at an early age (Dorries, Schmidt, Beauchamp, & Wysocki, 1989), and apply more specifically to discrimination, recognition and identification abilities (Doty, 1997; Wysocki & Gilbert, 1989), as well as the accuracy of higher order olfactory processing, such as naming or memory tasks (Good & Kopala, 2006). The effect size of this difference increases with age (Ship and Weiffenbach, 1993), and is consistent across cultures (Barber, 1997; Doty et al., 1985). Although women detect pleasant and unpleasant odours faster than neutral ones, this is not the case for men (Pollatos et al., 2007). Neither Chen and Dalton (2005), nor Pollatos et al. (2007) found a difference in perceived pleasantness and arousal between men and women. In general, women are more sensitive to biologically relevant olfactory stimuli, such as the pheromone Androsterone (Wysocki & Gilbert, 1989). This last point, when combined with women's peek sensitivity to olfactory stimuli during the pre-ovulatory period (Good & Kopala, 2006), and the passive communication of mate quality through body odour (Sergeant, Davies, Dickins, & Griffiths, 2005), supports the biological relevance of the superior sensitivity of the woman's olfactory system.

Emotional states

Current emotional states also seem to influence olfactory processing (Pollatos et al., 2007). While an individual's current emotional state does not seem to affect olfactory discrimination, it seems that across both sexes, negative emotional states are associated with an increase in judged odour intensity; for men, this increase in judged odour intensity is observed across all emotional conditions (Chen & Dalton, 2005; Pollatos et al., 2007). Viewing pleasant and unpleasant pictures, respectively, increases and decreases the pleasantness ratings of a neutral suprathreshold odour judged according to intensity and pleasantness (Pollatos et al., 2007). The viewing of unpleasant pictures is followed by significantly reduced olfactory sensitivity (Pollatos et al., 2007). This result is congruent with the effect of negative emotional states on the ”primary sensory level of stimulus processing as measured by threshold tasks” (Pollatos et al., 2007, p. 587-588), as previously demonstrated with depressive patients (e.g., Serby, Larson, & Kalkstein, 1990; Pause et al., 2003). Song and Leonard (2005) suggest that, considering the projection of the olfactory system onto the limbic system (in particular, the orbitofrontal cortex and the amygdala), there could be a link between the dysfunction of a depressed patient's limbic system and the reduced olfactory sensitivity. Interestingly, Vasterling, Braily, and Sutker (2000) found that patients with PTSD suffered from olfactory identification deficits (an observation which Doop, Mohr, Folley, Brewer, and Park (2006) report as consistent with PTSD related dysfunction of the fronto-limbic system). These findings could be considered contradictory to the use of olfactory cues in the treatment of PTSD; this apparent contradiction will be addressed in the next section.

Visual stimuli

Multisensory integration is a “process by which inputs from one sensory modality influences processing of information from another modality and leads to either enhanced or dampened neural responses depending on the variety of factors, such as context and temporal or spatial concordance” (Small, 2004, p. 120). This process implies that “when two or more sensory cues occur at the same time and in approximate spatial correspondence, the firing rate of a multisensory neuron to a stimulus in one modality can be measurably altered by the presence of a second stimulus in another modality” (Österbauer et al., 2005, p. 3434). Anatomical and physiological evidence suggests that the multisensory integration of olfactory and visual stimuli involves the orbitofrontal cortex and the amygdala (Thesen et al., 2004). There seem to exist compelling colour-smell associations (Österbauer et al., 2005). Indeed, colour not only facilitates odorant identification, but it can also influence judgments of odour intensity and pleasantness (Zellner, Bartoli, & Eckard, 1991). The mere presence of colour in an odorant-less solution increases the likelihood that subjects will report an odour (Engen, 1972), and a seemingly impossible colour-smell combination (such as red coloured white wine) can create perceptual olfactory illusions (DuBose, Cardello, & Maller, 1980; Morrot, Brochet, & Dubourdieu, 2001). So far, however, the literature offers little evidence whether odours can, in turn, influence visual perception (Thesen et al., 2004).

In summary, women’s olfactory processing seems more sensitive than that of men, and negative emotional states are associated with an increase in judged odour. Although the gender related difference in olfactory processing may not necessarily warrant the development of gender specific olfactory environments, it may need to be taken into consideration during the analysis of the effect of odorants during immersion. Most importantly for the integration of olfactory cues in VEs, visual stimuli seem to influence and enhance olfactory processing.

The influence of odours on perception and mental processes

A variety of studies demonstrate that olfactory cues can exert a cross-modal influence on the judgement of a variety of non-olfactory stimulus attributes/qualities (Demattè, Österbauer, & Spence, 2007).

Odours, emotions, and arousal

Pleasant and unpleasant odours cues have the power to lead to, respectively, positive and negative affective states (Ehrlichman & Halpern, 1988) and moods (e.g., Alaoui-Ismaïli et al., 1997; Goel & Grasso, 2004). Specifically, it has been demonstrated that pleasant odours decrease arousal, whereas unpleasant odours have opposite effects (e.g., Knasko, 1992; Alaoui-Ismaïli et al., 1997). Furthermore, arousal seems to be positively correlated with the strength of an odour (e.g., Royet et al., 2003; Heuberger, Hongratanaworakit, & Buchbauer, 2006).

Odours and pain

Odours seem to have the potential to increase and decrease the perceived pain. Familiar odours, such as maternal milk odorant (Mellier, Bézard, & Caston, 1997; Rattaz, Goubet, & Bullinger, 2001), can soothe up to moderate pain in infants, thereby limiting or even preventing crying and thus, limit the energy expended during somewhat painful medical procedures (Goubet, Rattaz, Pierrat, Bullinger, & Lequien, 2003). Conversely, to an already existing pain, certain odours seem to superimpose an additional pain, and slowly increase the level of background pain (Villemure, Wassimi, Bennett, Shir, & Bushnell, 2006). Neurophysiologically, the intensification in perceived pain can be observed by increased neural activation in several areas associated with pain (Villemure et al., 2006). However, although the unpleasantness of the odour predicts the increase in pain intensity and unpleasantness, it is the changes in mood evoked by the odours that correlates best with the level of pain (Villemure et al., 2006).

Odours and social interaction

The perceived masculinity/femininity of photographed faces can be influenced by the presence of human sex hormone-like chemicals (Kovács et al., 2004). These findings are in line with results suggesting the influence of human pheromones on people's judgments of the written descriptions of others (Cowley, Johnson, & Brooksbank, 1977), and on the ratings of the sexual attractiveness of pictures of women (Kirk-Smith, Booth, Carroll, & Davies, 1978; Kirk-Smith & Booth, 1990). Pheromones, which humans emit in all body fluids (Ratey, 2001), are also processed via the olfactory system (Stockhorst & Pietrowsky, 2004). Even though they may carry no consciously perceptible odour, they can cause measurable changes in the autonomic nervous system and, depending on the pheromone, they can induce mild impressions of contentment or uneasiness (Ratey, 2001). Evidence suggests that pheromones affect human sexual behaviour, not through sexual activity per se (Stockhorst & Pietrowsky, 2004), but through the modification of socio-sexual mating preference, attractiveness and mood (Cutler, Friedmann, & McCoy, 1998). More specifically, they "facilitate the perception of species members for reproduction (Cowley & Booksbank, 1991; Wyatt, 2003), they lead to an entrainment of the menstrual cycle (Stern & McClintock, 1998), change the physical attraction of the possible sexual partners (e.g., Kohl, Atzmüller, Fink, & Grammer, 2001; Grammer, 1993) and mood (Jacob & McClintock, 2000), and they are correlated to physical attractiveness (Rikowsky & Grammer, 1999)" (Stockhorst & Pietrowsky, 2004, p. 5).

Research results also suggest a tendency to rate other people more positively when in the presence of a pleasant fragrance (e.g., Kirk-Smith & Booth 1990). In turn, there is a significant positive correlation between the rated sexiness of a man's body odour and his facial attractiveness to females (Rikowski & Grammer,1999). However, Demattè et al. (2007) suggest that odours do not affect the actual perception of the visual characteristics of a subject, but that instead, they change the affective reaction to them.

Odours, learning, and conditioning

Indicators supporting the role of learning in olfaction include an improving ability to discriminate between two previously unfamiliar odorants with exposure (Rabin, 1988; Jehl, Royet, & Holley, 1995), and the ability to acquire the qualities used to describe an odour (Stevenson, 2001). Olfactory learning appears to take place as early as the olfactory bulb and the pyriform cortex (Brennan & Keverne, 1997; Haberly, 2001). This process permits the fine tuning, amplification and storage of the particularly important odours, thus allowing the subject to distinguish them from the multitude of olfactory stimuli in the environment (Hudson & Distel, 2003). Learning greatly affects the perception and processing of odours, and it allows an organism to associate a specific situation with a particular smell (Stockhorst & Pietrowsky, 2004). It may be the processes of amplification and storage of odours (identified as particularly important through "learning" during a traumatic event) that, despite the previously mentioned findings of olfactory identification deficits in PTSD patients, make the use of trauma related odorants pertinent in the treatment of this category of clientele. As demonstrated by one trial aversions against smells (and tastes) associated with nausea-inducing substances, olfactory learning can take place in the form of one trial classical conditioning (Stockhorst & Pietrowsky, 2004).

Olfactory conditioning appears to first have been demonstrated on humans by Kirk-Smith, Dodd and Van Toller (1983), and by Marinkovic, Schell, and Dawson (1989), as well as by Moore and Murphy (1999). Respectively, they successfully paired an odorant with an elevated level of anxiety, physiological arousal, and an eye-blink response. Olfactory stimuli may also, by virtue of an association with unconditioned drug stimuli, elicit conditioned responses in the form of increased craving, skin responses and heart rate changes (Bordnick et al., 2008). Olfactory conditioning seems to contribute to the phenomena of sick building syndrome and multiple chemical sensitivities (Magnavita, 2001). Various investigations (e.g., Van den Bergh et al., 1999) suggest that the somatic negative symptoms in reaction to certain chemicals are most likely linked to conditioned increases in olfactory sensitivity to those same chemicals (Chu, 2008), potentially leading to reactions such as pre-chemotherapy nausea (Siegel, 1999). Olfactory conditioning has also emerged as an influence in drug administration (Stockhorst et al. 1999) and cigarette smoking behaviour (Lazev, Herzog, & Brandon, 1999).

Herz, Schlanker, and Beland (2004) have suggested that ambient odorants, initially paired with seemingly easy but actually impossible to complete tasks, could have an influence on behaviour. In one of their experiments, they exposed their participants to an unfamiliar ambient odorant during a frustration mood induction; when the participants later worked on puzzle tests in a room scented with either the same-odorant, a different-odorant, or no-odorant, participants in the same-odorant condition spent significantly less time working on the tests than participants in the other conditions. Herz, Schlanker et al. (2004) suggest the existence of emotional conditioning mechanism: the reduction in the time spent on the task, in presence of the conditioned odour, is the result of a reduced motivation, itself resulting from the odour triggered re-emergence of the negative emotional reaction initially experienced during the failure to complete seemingly easy tasks. But the opposite also seems to be true. Indeed, Chu (2008) demonstrated that, by classically conditioning an odorant with positive task-related experiences, subsequent performances of underachieving schoolchildren could be manipulated to significantly improve on subsequent tasks. An olfactory stimulus can also act as a conditioned stimulus in fear conditioning (Engen, 1973), and Chu (2008) suggests that stronger emotions increase the likelihood of effective olfactory associative links.

Odour and memory

Lehrner et al. (1999) report evidence supporting the existence of a discrete olfactory memory system branching into component subsystems. Olfactory memory is independent of, and different, from other modalities of memory (Vermetten & Bremner, 2003). Common and complex odorants are encoded and remembered as poorly as abstract meaningless geometrical shapes (Lawless, 1978); Lawless (1978) and Engen (1991) suppose that the lack of structural information in olfactory stimuli could contribute to the poor immediate recognition of odours (in comparison to visual and verbal stimuli). Odour memory seems strongly affected by proactive interference (Engen, 1987; Lawless & Engen, 1977), barely affected by the effect of learning strategies (Zucco, 2007), and very resistant to retroactive interference (Lawless & Engen, 1977; Zucco 2007). As such, it may well be the absence of attributes that contributes to its resistance to interference (Schab, 1991). Although Engen and Ross (1973) had proposed that odours are encoded in relation to perception and independent of semantic networks, Royet et al. (1999) found that semantic and perceptual subsystems interacted during odour processing (Doop et al., 2006).

According to Engen and Ross (1973), there seems to be no difference between the recognition rates of intentionally and incidentally learned odour. In addition, the memory of an odour seems unaffected by higher order abilities (Danthiir, Roberts, Pallier, & Stankov, 2001). Although Engen and Ross (1973), as well as Lawless and Cain (1975), had found no link between familiarity and odour memory, more recent sources have suggested that familiar odours are easier to remember and discriminate than unfamiliar ones (Savic & Berglund, 2000; Schab & Crowder, 1995). Royet et al.'s (1999) finding that odour familiarity strongly predicted odour naming further supports the link between familiarity and odour memory. Anatomical support to this result includes the observation that the judgement of odour familiarity involves the left inferior frontal gyrus (Royet et al., 1999), an area normally linked to semantic association (e.g., Ricci et al., 1999; Vandenberghe et al., 1996). Thus, familiar and unfamiliar odours may be mediated by separate neuronal circuits (Savic & Berglund, 2004). Furthermore, if familiarity and pleasantness are indeed correlated (as suggested by Bensafi et al., 2002; Sulmont et al., 2002), then odour pleasantness may also affect odour memory.

While the memorisation of a new odour seems more difficult than that of visual and auditory stimuli, if it is successfully stored, the memory of that odour is particularly persistent (e.g., Herz & Engen, 1996; White, 1998). During recognition tasks immediately after exposure to stimuli, visual and auditory stimuli are recognized at a rate of 90% (Zucco, 2007), while olfactory stimuli are recognized at a rate of only 70% (e.g., Herz & Engen 1996; Zucco 2003, 2005). However, over an entire year, unlike it is the case for verbal and visual stimuli, the forgetting curve of an acquired odour is relatively flat (e.g., Engen & Ross, 1973; Nickerson & Adams 1979). In fact, Engen and Ross (1973) observed that after one year, over and above the 30% recognition rate lost during initial memorisation, the recognition rate of odorants only decreases by an additional 5%.

Odour memory is excellent for odours associated with significant autobiographical experiences (Engen, 1973). This is supported by the ability of certain adults to name odours they had not smelled since childhood (Goldman & Seamon, 1992), and may be influenced by the aforementioned strong resistance to retroactive interference. Autobiographical memories are "episodic memories: recollected events that belong to an individual's past. The events that are recalled as autobiographical memories are typically multimodal (involving vision, hearing, smell, taste, touch, and body sense or kinesthesis); they vary in spatial, temporal, emotional, and narrative content and context; they have personal relevance" (Rubin, 2005, p. 79), and they are usually encoded passively (Chu & Downes, 2000a). Thus, the systems that play a role in autobiographical memory are the individual senses, a multi-modal spatial system that notes the location of people and objects, emotion, language, a non language narrative system which tracks causal relations (Rubin, Schrauf, & Greenberg, 2003; Schrauf & Rubin, 2000), and "an explicit memory system that coordinates or binds information from the other systems" (Rubin, 2005, p. 79). When auto-biographical and semantic memory retrievals are compared, the amygdala, the hippocampus and the right inferior frontal gyrus were found to be more active (Rubin, 2005), and working closely together (Greenberg et al., 2005) during the former.

Autobiographical memory retrieval is enhanced by exposure to event associated odours (Doop et al., 2006). In an autobiographical memory recall task, twice as many memories were recalled when accompanied with the appropriate odorant than without (Maylor, Carter, & Hallett, 2002). Odour-evoked memories seem different from other memory experiences (Willander & Larsson, 2006). Although they are no more accurate than those evoked by other senses (Herz, 2004), odorant triggered memories are rated as more pleasant, and recalled less frequently (Rubin, Groth, & Goldsmith, 1984). Odour representations can be recalled after longer periods of time than verbal or visual ones: while visually and verbally triggered memories generate a reminiscence bump between the ages of 10 and 30 years at event (e.g., Conway & Haque, 1999; Rubin, Rahhal, & Poon, 1998), olfactory triggered memories have been localised to the first decade of life (Chu & Downes, 2000b; Willander & Larsson, 2006). These results are in agreement with research suggesting that associative olfactory learning begins very early in life (Schaal, Marlier, & Soussignan, 2000; Van Toller & Kendal-Reed, 1995), and earlier than the formation of auto-biographical memories consisting of verbal or visual information (Willander & Larsson, 2006). The strength of the relationship between the olfactory cue and the autobiographical memory is directly correlated to the emotional charge and significance of the remembered event (Vermetten & Bremner, 2003). The remarkable ability of olfactory stimuli to evoke very old autobiographical memories may be attributed to weak retroactive interference (Lawless & Engen, 1977), strong proactive interference and, when compared to visual or auditory stimuli, a low probability of subsequent exposure interference (Herz, 2004). Consequently, the first odour/event association is very hard to unlearn, a subsequent association to the same odour is difficult to form (Herz, 2004), and hence, exposure to event-congruent olfactory information can give access to very old personal experiences (Willander & Larsson, 2006).

In addition to being more potent autobiographical memory cues than stimuli presented to other senses (Chu & Downes, 2000), research suggests that olfactory triggered memories generate a stronger feeling of being brought back in time, than verbally or visually triggered ones (e.g., Herz, 2004; Willander & Larsson, 2006). Indeed, cross-modal laboratory and autobiographical studies of episodic memory have shown that olfactory triggered memories are more vivid than memories evoked by corresponding words (Chu & Downes, 2002), and more emotional than those triggered by alternate sensory variants (including, auditory stimuli; Royet et al., 2000) of the same item (e.g., Herz, 2004; Herz, Eliassen, Beland, & Souza, 2004). In fact, specific trauma related olfactory cues can lead to anxiety, fear related memories, flashbacks

(Vermetten & Bremner, 2003) and panic attacks (Hinton, et al., 2004) in PTSD patients; these reactions may, in turn, lead to avoidance behaviour. In the case of PTSD, the conditioned responses rooted in the auto-biographical memory do not extinguish with time (Vermetten & Bremner, 2003). These observations are congruent with the direct synapsing from the olfactory area to the amygdala-hippocampal complex (neural substrate of emotional memory) (Cahill, Babinsky, Markowitsch, & McGaugh, 1995; Herz, Eliassen, et al., 2004), and the greater activation in the amygdala-hippocampal complex in reaction to personally relevant odours (Herz, Eliassen, et al, 2004).

Effect of sub-consciously processed odours

The research presented above suggests that olfactory processed signals can affect organisms, but it is important to recognize that these signals need not be consciously processed to create an effect. Indeed, subliminal odours (as little as 7 ppt; Shepherd, 2004) can influence implicit odour memory (Degel & Köster, 1999; Köster, Degel, & Piper, 2002), social likeability judgments, and autonomic responses in a valence-consistent manner (Li, Moallem, Paller, & Gottfried, 2007). In fact, contrary to autonomic responses which are independent of the level of awareness of an odour, the effects on social likeability emerge best when the odour is subliminal (Li et al., 2007). As bottom-up sensory input often induces top-down regulation, thereby resulting in synthesized processes (Schneider & Chein, 2003), it has been suggested that it is the absence of the conscious awareness of the odour, and thus the absence of a top-down regulation, that allows the subliminal odour to exert a greater effect than supraliminal odours (Li et al, 2007).

In summary, the presence of an odorant is associated with numerous effects, and some of the ways these effects could be exploited in VEs will be addressed in the discussion section.

While pleasant odours seem to lead positive affects and decrease arousal, unpleasant ones seem to increase arousal and lead to negative affects. Furthermore, arousal is inversely related to pleasantness, but positively related to odour strength. The presence of odours can increase or decrease the pain perceived by an individual. The indications that an odour can influence how another person is perceived are of particular interest to social presence in a VE; these results seem to speak in favour of assigning individual olfactory signatures to each virtual human in a particular VE. Olfactory learning enables the discrimination of odorants in the environment, and this ability can be improved through exposure. Olfactory conditioning - the association between an olfactory stimulus and a particular situation - can not only elicit physiological and physical responses, but it can also affect performance. The olfactory system seems to have its own memory system, and although the establishment of the memory of an odour is more difficult than that of a visual stimulus, if it is successfully established, it becomes particularly persistent. There seems to be no difference between the recognition rates of intentionally and incidentally learned odours, and the memory of an odour seems unaffected by higher order abilities. Odour memory is excellent for odours associated with significant autobiographic experiences, and the retrieval of an autobiographical memory is enhanced by exposure to event associated odours. The strong resistance to retroactive interference allows olfactory cues to trigger memories originating in the first 10 years of life; these memories are vivid, and give a strong feeling of being brought back in time. The conscious awareness of the odour is not necessarily required to enable its potential effects.

Discussion

The sense of olfaction is used constantly and often sub-consciously (Drummond et al., 2007). It contributes to personal safety by helping to test the quality of the air (Drummond et al., 2007), detect the presence of food and individuals (Drummond et al., 2007), determine the edibility of food (Holland, Hendriks, & Aarts, 2005), sense the flavours of food (Ratey, 2001; Shepherd, 2006), to the pleasures of eating (Simpson & Sweazy, 2006), and thus, it influences also future consumption. The olfactory sense's significant role in human social behaviour is supported by the observation that, contrary to congenitally blind, mute or deaf people, individuals with congenital anosmia do not have intact reproductive–social behaviour (Naftolin, Harris, & Bobrow, 1971). The olfactory sense contributes to the identification of, not only an individual, but also his/her gender (Russel, 1976), as well as certain emotional states (Stockhorst & Pietrowsky, 2004). Subconsciously, it affects mating behaviour (e.g., Herz & Inzlicht, 2002; Sergeant et al., 2005); specifically, it influences attraction and sexual partnering by affecting mood states (Jacob & McClintock, 2001), detecting immune system characteristics (Jacob, McClintock, Zelano, & Ober, 2002; Thornhill & Gangestad, 1999), genetic similarities (Eggert, Müller-Ruchholtz, & Ferstl, 1999), and female fertility (Poran, 1995). As presented earlier in this document, research results suggest that through the association of an olfactory cue with an emotion (the more intense the emotion, the stronger the association), that same olfactory cue can later evoke the conditioned emotion, thereby affecting the abilities and behaviour of the subject. Thus, it could be expected that the use of olfactory cues would be common in experimental as well as in clinical psychology; yet it isn't so.

Several factors may have contributed to this situation. First and foremost, as olfaction often acts subliminally, its importance in day-to-day life may be underestimated (Albrecht & Wiesmann, 2006). Secondly, due to their complex composition and transient character, the controlled exposure to olfactory stimuli is more complex than that to visual or acoustical stimuli (Stockhorst & Pietrowsky, 2004) and it is still impossible, from one exposure to another, to stimulate the exact same combination of olfactory receptors (Hudson & Distel, 2003). Thirdly, the odour perceived by each subject is highly subjective, and thus, generalisation involving one particular odorant is likely to be difficult. These factors may have contributed to the knowledge gap between olfaction and the more researched senses such as vision and audition; this knowledge gap also applies to the technology behind the devices reproducing and dispensing olfactory stimuli.

But more recently, due to the potential of this relatively neglected sense and, in particular, its ability to evoke vivid memories, this trend has begun to change (Chu & Downes, 2000a). Today, in the field of scent machines, dispensing and controlling odorants in VEs (previously identified, as the primary obstacle to a generalised integration of olfactory stimuli in VEs; Sadowski, 1999) are being addressed by a variety odour delivery systems (e.g., the SDS100 by Biopac Systems Inc., the Scent Collar by the Institute for Creative Technologies in collaboration with AnthroTronix Inc., and the Scent Projector by Media Information Science Laboratories); these systems allow exposure to a variety of orthonasally delivered olfactory stimuli. In the field of applied research, the interest in aromachology, the study of the influence of odours on behaviour, now grows annually, and the topics covered by this research include the effect of odorants on emotions, physiology, cognitive abilities and behaviour (Chu & Downes, 2000a). It has been suggested that a jasmine scent can enhance individuals' performance on problem-solving tasks, as well as lead to higher levels of interest and motivation to a task (Rottman, 1989), and that the scents of rose and mustard seed differentially modulate attention to brightness (Michael, Jacquot, Millot, & Brand, 2003). A stimulating peppermint fragrance seems to contribute to increased pain tolerance (Raudenbush, Koon, Meyer, & Flower, 2002), to enhance athletic performance (Raudenbush, Meyer, & Eppich, 2002; Raudenbush, Corley, & Eppich, 2001), to induce physiological arousal (Raudenbush, Koon, et al., 2002), and to enhance attention to visual stimuli (the latter also seems true for muguet; Warm, Dember, & Parasuraman, 1991). Finally, a rosemary scent seems to contribute to, at the cost of slower performance, increased memory recall accuracy (Moss, Cook, Wesnes, & Duckett, 2003), while a cinnamon scent seems to contribute to enhanced cognitive performances such as attention processes, virtual recognition memory, working memory, and visual-motor response speed (Zoladz & Raudenbush, 2005). Some of the physiological changes resulting from pleasant ambient scents may, in turn, contribute to behaviours such as increased gambling in casinos (Hirsch, 1995), increased time spent on a decision task (Bone & Ellen,1999; Mitchell, Kahn, & Knasko, 1995), and intentions to visit a store (Spangenberg, Crowley, & Henderson, 1996). At the opposite side of the spectrum, the persistent scents of air pollution seem to contribute to aggression in school aged children (Ratey, 2001). Other results indicate that odours can impair the memory for faces that are presented simultaneously with an odorant (Walla et al., 2003), and that when an odour is semantically (Platek, Thomson, & Gallup, 2004) or hedonically (Ehrlichman & Halpern, 1988) congruent with a picture or a word, it facilitates the detection of that picture, or the production of that word. Furthermore, stimulating odorants seem to have the ability to increase alertness (Goel & Lao, 2006; Weber & Heuberger, 2008).

In clinical applications, aromatherapy aims to capitalize on the ability of olfactory stimuli to elicit specific emotional responses. It relies on the hypothesis that, due to the rapid connection between the olfactory system and the limbic system, the appropriate olfactory stimulus could calm or stimulate an individual, assist sleep, influence eating habits, reduce pain (via the release enkephalins), or heighten sexual arousal (via the release of endorphins) (Ratey, 2001). For example, the natural scent of blooming plants seems to be able to increase calmness, alertness, and mood (Weber & Heuberger, 2008), while a lemon scent seems to lead to fewer reports of health symptoms (Knasko, 1992).

Whether in clinical or experimental research, VEs have, so far, failed to fully integrate the potential of olfactory stimulation; but there are exceptions. In clinical scenarios, some interesting VR research utilising olfactory stimuli is being pursued in the field of behavioural and physiological reactivity to drug and alcohol triggers/cues (e.g., Bordnick et al., 2008). In such scenarios, the power of combining visual and olfactory cues to induce drug craving and undesired behaviour can be employed as a tool for behaviour modification. Clinical scenarios for treating PTSD utilise the tendency of prevailing olfactory cues to become strongly associated to a co-occurring and highly emotional event (such the odour of burning human flesh during a Rocket Propelled Grenade attack on a convoy). In these virtual world scenarios, olfactory cues, along with visual and acoustic ones, are meant to ease access to, and thus facilitate the processing of, traumatic memories (e.g., Gerardi, Rothbaum, Ressler, Heekin, & Rizzo, 2008).

However, the use of olfactory cues in VEs is closer to exception than rule, and more extensive applications of olfactory cues seem possible. For example, VEs are presently used for pain distraction (e.g., Hoffman, Patterson, & Carrougher, 2000), and odours seem to have the potential to decrease perceived pain; it would be interesting to verify the effect of integrating them in these types of applications. Furthermore, Kawai and Noro (1996) have suggested that odorants, combined with stereoscopic 3-D images may, through their ability to affect arousal and emotions, be useful in relaxation procedures; it seems that, as an extension of this application, the investigation of the use of olfactory cues as an element of treating mood disorders in VEs would also be pertinent. In training scenarios, VR olfactory conditioning could turn out to be useful in triggering more appropriate responses to emergency situations; for example, the use of the smell of smoke, during the practice of a fire drill in a VE, may lead to more appropriate behaviour (including the control of emotions) in the presence of this stimulus during an actual fire. Olfactory cues in a VE may also turn out to be useful to establish an association between a distinct odorant and "virtually evoked" positive emotions; such an association may, possibly, find use in relaxation training, or the treatment of certain mood and anxiety disorders. Furthermore, the ability of a VE to expose a great number of users to a complex, yet perfectly identical scenario, would seem to make it a good tool for investigating the fundamental interactions between olfactory cues, perception, cognition, emotion, and behaviour. The results of such investigations seem of major interest, because they could reveal whether the integration of olfactory stimuli in training devices, such as combat simulators, would enhance the virtual experience, and if so, how and by how much.

Conclusion

In sum, research has demonstrated the importance of olfactory stimuli in the human experience, and the results suggest that until olfactory cues are properly integrated in VEs, the gap between real world and virtual world experiences will remain significant. It is likely that the proper integration of olfactory cues in VEs will bring scenario simulation (whether for training or therapeutic purposes) to a previously unattainable level of realism.

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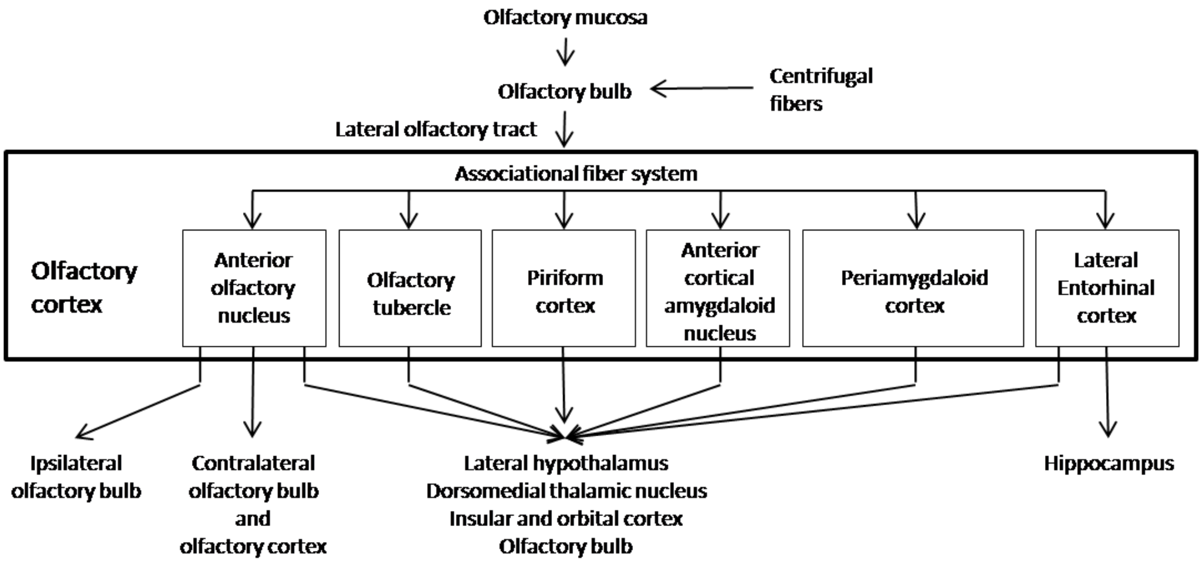
Figure Captions

Figure 1. Major projections of the olfactory cortex (Simpson & Sweazy, p. 371, 2006).


Olfactory mucosa
Olfactory bulb
Centrifugal fibers
Lateral olfactory tract
Associational fiber system
Olfactory cortex
Anterior olfactory nucleus
Olfactory tubercle
Piriform cortex
Anterior cortical amygdaloid nucleus
Periamygdaloid cortex
Lateral Entorhinal cortex
Ipsilateral olfactory bulb
Contralateral olfactory bulb and olfactory cortex
Lateral hypothalamus
Dorsomedial thalamic nucleus
Insular and orbital cortex
Olfactory bulb
Hippocampus

Supplement to the article

The Sense of Olfaction:

Its Characteristics and Its Possible Applications in Virtual Environments

(Baus & Bouchard, 2010)

The purpose of this section is to supplement the article "The Sense of Olfaction: Its Characteristics and Its Possible Applications in Virtual Environments (Baus & Bouchard, 2010) by providing the reader with an update regarding recent reviews of the human olfactory system. To this end, articles reviewing olfaction were searched in Scopus from 2010 to present with the key term "olfact*". Publications dealing with topics outside the scope of Baus and Bouchard (2010) were excluded.

While readers specifically interested in a review of the anatomic pathways of olfaction may want to refer to Patel and Pinto (2014), those looking for a summary of the recent developments in the understanding of olfaction could consult Auffarth (2013). Furthermore, Wittmann-Price (2012) provides an interesting review and discussion regarding the development and assessment of the human olfactory function through the lifespan, and readers looking for a review of the olfactory system from an anthropological point of view may be inclined to turn to Hoover (2010). Some interesting research has also been published regarding the importance of olfaction in various aspect of human life. They include Sethi (2013) who provides a review and discussion on the role of olfaction in feeding, mating and safety in both human and animals, Hanci and Altun (2016) who report on the effect of hunger on olfactory abilities, Hoskison (2013) who examines the influence of olfaction and pheromones on life, and Rolls (2015) who reviews the interaction between taste, smell, and food reward value processing in the brain. Overall, these publications provide further confirmation of the importance of smell in day-to-day life, and they tend to support Baus and Bouchard's (2010) hypothesis that the integration of olfactory cues in virtual reality (VR) could improve a user's experience.

A thought-provoking line of research examines the potential links between olfaction, attention and consciousness. While Stevenson (2011) reviews the empirical literature regarding olfactory illusions, Merrick and colleagues discuss how the properties and aspects of the olfactory system can illuminate the contrast between conscious and unconscious processing in the brain (Merrick, Godwin, Geisler, & Morsella, 2014), and Keller (2011) reviews the mechanisms and neuroanatomy of attention and consciousness in the olfactory system. Pursuing this novel field of research linking olfaction, attention and consciousness could become of particular interest in order to understand how consciousness in general, and the consciousness of the presence of a particular odour may affect a user's experience in VR.

The factors that affect the olfactory sense is a line of research pursued by a number of authors. While some review a broad spectrum of factors that can affect the sense of olfaction, others focus on specific conditions. For example, Gaines (2013) provides a chapter on olfactory disorders as well as their potential causes, while Hong and colleagues review and discuss the clinical understanding of olfactory distortions as well as their evaluations and therapies to treat them (Hong, Holbrook, Leopold, & Hummel, 2012). Doty and Kamath (2014) review the multiple factors that contribute to age related decreases in olfactory function, while Ottavio and colleagues focus in on the association between (often age related-) neurodegenerative diseases and smell dysfunction (Ottaviano, Frasson, Nardello, & Martini, 2016). Given the present day's increasing proportion of senior citizens, understanding the link between olfactory dysfunction and neurologic/neurodegenerative diseases has led a number of authors to research the question. They include Lucassen, Turel, Knehans, Huang, and Eslinger (2016), Godoy, Voegels, Pinna, Imamura, & Farfel (2015), Kovács (2013), Puschmann and Wszolek (2013), Doty (2012), Haehner, Hummel, and Reichmann (2011), Haehner, Hummel, and Reichmann (2011), as well as Morley and Duda (2010). Taken as a whole, these studies confirm that conditions such as Multiple Sclerosis, Parkinson's disease and Alzheimer can lead to olfactory dysfunction.

In their article, Baus and Bouchard (2010) reported on the link between current emotional states and olfactory processing. Soudry and colleagues provide a useful complement to Baus and Bouchard (2010) by shedding some light on the common substrates of the central olfactory pathways and the centers involved in emotional analysis (Soudry, Lemogne, Malinvaud, Consoli, & Bonfils, 2011). Given this anatomical link, other authors have examined the link between the olfactory function and psychological/psychiatric disorders. For example, Burón and Bulbena (2013) review olfactory function in affective and anxiety disorders, Yuan and Slotnick (2014) examine the role of the olfactory system in depression, Schablitzky and Pause (2014) examine the reduced olfactory sensitivity related to major depressive disorder, and Schecklmann and colleagues provide a systematic review on olfaction in child and adolescent psychiatric disorders (Schecklmann, Schwenck, Taurines, Freitag, Warnke, Gerlach, and Romanos, 2013). Finally, Nguyen, Shenton, and Levitt (2010) summarize recent research on neuroimaging changes associated with olfactory impairments in schizophrenia patients, and Rupp (2010) reviews olfactory deficits, abnormalities, and olfactory hedonic dysfunction in schizophrenia.

As reported by some authors, olfactory dysfunction can also result from physical trauma. More specifically, Schofield, Moore, and Gardner (2014) provide a systematic review of studies concerned with olfactory functioning following traumatic brain injury. Bakker, Catroppa, and Anderson (2014) report on that same topic, but specifically in a child population. Other medical conditions having been linked to olfactory dysfunction include chronic rhinosinusitis (Rombaux, Huart, Levie, Cingi, & Hummel, 2016), and migraine (Sjöstrand, Savic, Laudon-Meyer, Hillert, Lodin, & Waldenlind, 2010).

Finally, the effect of olfactory stimuli on physiology as well as their potential use in clinical applications is another promising area of research. While Angelucci and colleagues provide an overview of the physiological effect of olfactory stimuli (Angelucci, Silva, Dal Pizzol, Spir, Praes, and Maibach, 2014), Nagai and colleagues specifically report on the effects of olfactory stimulation with grapefruit and lavender oils on autonomic nerve activity and physiological function (Nagai, Niijima, Horii, Shen, & Tanida, 2014). Readers interested in the olfactory sense and its clinical applications may want to look at Horowitz (2014).

In conclusion, results from recent research on olfaction confirm and refine the findings reported by Baus and Bouchard's (2010). Furthermore, these findings increase the weight of the argument for including olfactory stimuli in VR applications. Indeed, the stimulation of the olfactory sense can affect humans in a variety of ways, however, some psychological, medical, and physical conditions have been shown to lead to olfactory dysfunction. These results underscore the importance of verifying the olfactory function of individuals participating to experiments investigating the effect of exposure to olfactory stimuli.

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Article 2

Exposure to an Unpleasant Odour Increases the Sense of Presence in Virtual Reality

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Abstract

While olfactory cues affect the everyday human experience in the physical world, few studies have empirically examined the effect they could have on the human experience in virtual reality (VR). This project aims to determine whether exposure to olfactory stimuli would affect the senses of Presence (primary measure), Reality, and Realism (exploratory measures) in VR. In a virtual kitchen devoid of obvious visual cues linking the visual scene to an odour, 3 groups of 20 randomly assigned participants (12 females and 8 males per group), unaware of the potential exposure to olfactory stimuli, were exposed to either ambient air, a pleasant odour, or an unpleasant odour. The results show that the unpleasant odour had a statistically significant effect on the sense of Presence (as measured by repeated brief measures of Presence and the Independent Television Commission Sense of Presence Inventory), but the pleasant one did not. The lower perceived intensity of the pleasant odour may have contributed to its lower detection rate which, in turn, may have contributed to the pleasant odour's lack of effect on the sense of Presence. Neither of the olfactory stimuli had an effect on the sense of Reality or the sense of Realism.

Keywords: virtual reality, presence, olfaction, odours, reality, realism

Exposure to an Unpleasant Odour Increases the Sense of Presence in Virtual Reality

Introduction

Odours play an important role in everyday life. While pleasant ones can lead to positive affective states, positive moods, positive ratings of other individuals, as well as to a lower sensation of pain, unpleasant ones have been shown to have the opposite effect (respectively, Alaoui-Ismaïli, Vernet-Maury, Dittmar, Delhomme, & Chanel, 1997; Alaoui-Ismaïli et al, 1997; Kirk-Smith & Booth, 1990; Rattaz, Goubet, & Bullinger, 2001). An odour can facilitate the retrieval of autobiographical memories of an event associated with that particular odour (Doop, Mohr, Folley, Brewer, & Park, 2006), and even lead to olfactory-conditioned reactions such as pre-chemotherapy nausea (Siegel, 1999). Odours can also affect behaviour. For example, while a pleasant odour can lead to increased gambling in casinos (Hirsch, 1995), an unpleasant one can contribute to aggression (Ratey, 2001). Yet despite these important potential effects (for review, see Baus & Bouchard, 2010), there have been relatively few instances of odours integrated in virtual reality (VR) applications. Furthermore, very few publications have addressed the question of how odours might affect the quality of the human experience in VR from an empirical point of view. It was the primary objective of this project to quantify this potential effect.

The goal of examining the effect of odours on the human experience in VR is to help give developers an indication of whether it is worthwhile integrating olfactory cues in VR applications. Are there potential benefits to the quality of human experience in VR? Do the characteristics of the odours need to be taken into account? For that, this project investigated the effect of exposure to pleasant and unpleasant odours on the senses of Presence (primary measure), Reality, and Realism (exploratory measures).

The senses of Presence, Reality and Realism

The term “Presence” originates from the term “Telepresence” (Minsky, 1980). In the context of the operation of a remote-controlled device (e.g., a remote demining vehicle), this term designates the illusion that, while looking at the live video feed sent by the device, the operator feels present at the location of the device. In essence, as the operator sees the essential parts of the device necessary to complete the task, they may have the impression of being embodied in the device (Sanchez-Vives & Slater, 2005). Initial research in this domain was motivated by the hypothesis that higher levels of Telepresence may improve the operator’s performance (Sheridan, 1992). The term “Presence” appeared with the development of VR. Virtual reality is an application which, in real-time, allows a user to navigate through and interact with a 3D computer-generated environment (Pratt, Zyda, & Kellecher, 1995). A virtual environment can be defined as a 3D computer-generated digital space comprised of electronically generated stimuli (Baus & Bouchard, 2014). It consists of elements which, although may look like their physical counterparts, are matterless. While Telepresence is associated with the illusion of being at a distant but real location, the term Presence designates the illusion of being in a virtual location, and thus, in a location that is neither close nor distant.

Numerous variations of the term Presence exist. They include Personal Presence (Heeter, 1992), Virtual Presence (Sheridan, 1992), Spatial Presence (Lessiter, Freeman, Keogh, & Davidoff, 2001; Schubert, Friedmann, & Regenbrecht, 2001), and Physical Presence (Lee, 2004). While the exact definition of Presence varies somewhat between authors, there is a certain consensus about some of its attributes, the sense of Presence is (a) a multi-dimensional construct composed of various subtypes of Presence (e.g., IJsselsteijn & Harper, 2001; Kalawsky, 2000); (b) a response to the immersive properties of a system (e.g., Slater, Lotto, Arnold, & Sanchez-

Vives, 2009); (c) the result of an interaction between the system-produced stimuli and user-related factors (thoughts, emotions, cognitions, behaviour; e.g., IJsselsteijn & Harper, 2001; Schubert, Friedmann, & Regenbrecht, 2001); and (d) an indicator of the degree of response the VE triggers in the user (e.g., Schuemie, 2003). For the purpose of this paper, the sense of Presence will refer to the impression of being *in* the VE (Heeter, 1992).

The sense of Presence is not to be confused with immersion. According to Slater and Wilbur (1995), immersion is a quantifiable aspect of the VR system; it encompasses factors such as (a) the degree of isolation of the user from non-synthetic stimuli; (b) the number of senses that the system stimulates; (c) the size of the projection surfaces; and (d) the resolution of the images. To these, Slater (2003) added factors such as the quality of the stimuli and precision of the motion tracking. While Presence is a psychological factor, immersion is a technological one, and the latter can affect the former (Thornson, Goldiez, & Le, 2009).

The senses of Realism and Reality are two other concepts often used to qualify a user's experience in a VE. The sense of Realism results from an evaluation of the level of convergence between the virtual stimuli (appearance, behaviour, etc.) and the user's expectations with respect to those stimuli (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000). The level of Reality refers to the degree to which the user experiences the immersion as real (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000).

In sum, the sense of Presence refers to the sense of being physically located in the VE, the sense of Reality refers to the impression that what is being experienced in the VE is veridical, and the sense of Realism refers to the degree to which the elements of the VE resemble their counterparts in the physical world.

Importance of the Sense of Presence

There is some consensus on the importance of the role played by Presence in experiencing a VE (e.g., Aymerich-Franch, 2010; Bouchard, St-Jacques, Robillard, & Renaud, 2008). One of the main advantages of VR lies in its ability to provide complex training environments and active learning experiences too dangerous to play out in the physical world (e.g., handling in-flight emergencies, such as an engine fire). During these learning experiences, Presence can act as a facilitator in the accomplishment of a VE's objective (van Schaik et al., 2004), increase the motivation to learn (Heeter, 2003), and increase learning itself (Schank, 1997). A high level of Presence makes the experience engaging and pertinent; it can trigger thoughts, emotions, and behaviours similar to those experienced in a non-synthetic environment (Mantovani & Castelnuovo, 2003). In turn, a subsequent and similar situation *in vivo* (in the physical world) can trigger the appropriate and timely reactions, as previously learned and practised *in virtuo* (in a virtual world; Mantovani & Castelnuovo, 2003). In sum, Presence can contribute to the efficacy of the training, as well as to the transfer of knowledge and skills acquired in the synthetic environment to the real world. Further to the positive impact that a high level of Presence can have on training applications, it opens the door to fundamental studies aimed at better understanding psychological and physiological processes in experimental scenarios that, in a non-synthetic environment, are difficult to repeat in a perfectly identical manner for each participant (Lombard & Ditton, 1997). As a consequence, the feeling of Presence has become a research topic of both theoretical and practical interest (Lombard & Ditton, 1997).

Factors Affecting the Sense of Presence

Many authors have found it pertinent to investigate the variables that may affect Presence. These can be categorized as individual (user-specific characteristics) and environmental (system-related characteristics) factors. The individual factors that have been found to affect the sense of Presence include age (Bangay & Preston, 1998), immersive tendencies (Witmer & Singer, 1998), levels of absorption (Lombard & Ditton, 1997), and immersion-related negative effects (Kennedy, Stanney, & Dunlap, 2000). Regarding environmental factors, Steuer (1995) suggested that an increased number of stimulated senses can affect Presence. More specifically, it has been reported that sound (Dinh, Walker, Song, Kobayashi, & Hodges, 1999; Gilkey & Weisenberger, 1995), spatialized sound (Hendrix & Barfield, 1996a,b), and tactile augmentation (Dinh, Walker, Song, Kobayashi, & Hodges, 1999; Hendrix & Barfield, 1996a; Hoffman et al., 1996; Meehan, Insko, Whitton, & Brooks, 2002) can increase Presence. In addition, the mobilization of the body (Slater & Steed, 2000; Slater, Steed, McCarthy, & Maringelli, 1998) and reduced dissociation between proprioception and the senses seem to have a positive effect on Presence (Slater, Usoh, & Steed, 1995; Usoh et al, 1999).

Olfactory Stimuli and the Sense of Presence

Based on the fact that an increased number of stimulated senses can contribute to a higher sense of Presence, one would anticipate that exposure to olfactory stimuli would contribute to greater Presence. This hypothesis has been proposed by various authors (e.g., Cater, 1992; Zybura & Eskeland, 1999; Lombard & Ditton, 1997; Washburn, Jones, Vijaya Satya, Bowers & Cortes, 2003; Chen, 2006). Barfield and Danas (1996) went so far as to suggest that the absence of olfactory stimuli in a VE actually constituted a shortfall in VR. Indeed, more often than not, a VE consists only of visual and auditory stimuli. These stimuli are distinct from those of the non-synthetic environment. Thus, they facilitate the sense of having left the non-synthetic world, and the sense of actually being in the synthetic world. However, unless the user is exposed to VE-distinct olfactory cues, he/she perceives no olfactory distinction between the synthetic and non-synthetic environments. In terms of olfaction, the transition from the physical world to the virtual world is not facilitated. In sum, Barfield and Danas (1996) suggest that the absence of olfactory stimuli causes a prejudice to the experience in the VE. However, despite theoretical interest in the relation between olfactory stimuli and the sense of Presence, very few publications address this aspect.

Of those that do, it seems that only one published study addresses the topic from an empirical perspective. This publication, by Dinh and colleagues (1999), aimed to establish whether visual details, coupled with the presence or absence of tactile stimuli, auditory stimuli, and olfactory stimuli could affect (a) recall of the experience in the VE and (b) the sense of Presence. The results of this between-group study of 322 participants assigned to 16 conditions suggested that exposure to an olfactory stimulus can have a statistically significant effect on recall of the experience in the VE. However, an examination of the link between exposure to an olfactory stimulus and Presence yielded only a statistically non-significant “trend.” More specifically, the results of two distinct 4-factor ANOVAs suggested that when the user was exposed to an odour of coffee, the average Presence scores did increase, both on a 1-item brief measure of Presence and a 13-item questionnaire; however, neither of these increases was statistically significant. A few methodological weaknesses warrant that the potential relationship be examined again. Firstly, to prevent potential biases, it may have been useful not to reveal to the participants that they would be exposed to olfactory stimuli. Furthermore, no measures seem to have been taken to (a) identify and exclude participants with olfactory deficiencies and

(b) control for group differences in stereoscopic acuity, immersive tendencies, absorption tendencies, and negative immersion-related effects.

A different study focusing on immersion, not Presence (Jones, Bowers, Washburn, Cortes, & Satya, 2004), examined the link between olfactory stimuli and immersion. In this experiment, three groups of participants played a video game projected onto a 5’ X 5’ screen. While the control group was exposed to no particular olfactory stimulus, the experimental groups were exposed to either an odour concordant with the visual scene (“Ocean Mist” when over the ocean and “Musty” when inside a fort), or an odour discordant with the visual scene (odour of Maple Syrup throughout all phases of the game). The results indicated that the three groups rated the VE differently, but that the exposure to the olfactory stimulus - be it concordant or discordant with the visual scene - did not have a statistically significant effect on the level of immersion. However, while the results are interesting and useful, the project addresses the potential link between olfactory cues and immersion, not Presence. Finally, the VE was only projected onto a 5’ X 5’ screen, and thus it could be suggested that, given limited immersion and the lack of 3D imaging, the system does not qualify as VR.

Hypothesis

In sum, while some authors suggest that exposure to olfactory stimuli should have an effect on the sense of Presence in VR, the few publications that have addressed the issue did not find a statistically significant link. However, some methodological weaknesses may have contributed to these results. Thus a re-examination of the relationship was deemed warranted, starting with the simple question: “does olfaction matter?”

The research hypothesis of this experiment stated that, even in the absence of evident visual cues that could link the visual scene to a particular odour, exposure to an olfactory stimulus, whether pleasant or unpleasant, would be associated with a statistically significantly higher level of Presence. Exploratory analyses were also conducted to examine whether there were links between (a) exposure to an olfactory stimulus and the sense of Reality and (b) exposure to an olfactory stimulus and the sense of Realism.

Method

Participants

Recruitment and inclusion criteria. The 60 participants (24 males and 36 females) were recruited on local university and college campuses via adverts and class visits. To be recruited, participants had to be functional in French and between the ages of 18 and 60. No compensation was offered in exchange for participation. The participants were randomly assigned (balanced with regard to gender) to one of three groups: the AMB group (exposure to ambient air), the PLE group (exposure to a pleasant odour), and the UNP group (exposure to an unpleasant odour). The group mean ages, dominant cultural influence (by continent), and highest level of education completed are shown in Table 1.

Exclusion criteria. Several factors relating to the sense of Presence and olfactory perception were controlled to reduce potential differences unrelated to the groups' treatment. In order to meet the objective of having gender-balanced groups of 20 participants, those disqualified during the protocol (e.g., cybersickness) were replaced with the next participant of the same gender.

Presence-related exclusion criteria. This category encompassed criteria that could unduly affect the level of Presence. It included poor stereoscopic vision (Freeman, Avons, Meddis, Pearson & IJsselsteijn, 2000; Hendrix & Barfield, 1996a) and excessive cybersickness (Kennedy, Stanney, & Dunlap, 2000). More specifically, participants with stereoscopic acuity worse than 50 seconds of arc as well as those experiencing a simulator sickness level in excess of 16 were excluded. Furthermore, as coming into contact with the physical world (e.g., the laboratory's wall) during immersion was likely to affect the level of Presence, participants who did so were also excluded.

Olfaction-related exclusion criteria. This category encompassed criteria related to olfactory perception. Participants unable to identify at least two of the three odours in the Quick Smell Identification™ Test were excluded. Furthermore, it was essential to the protocol that participants assigned to the pleasant odour condition actually perceived the odour as pleasant, and that those assigned to the unpleasant odour condition actually perceived the odour as unpleasant. If this was not the case, they were excluded and replaced with the next participant of the same gender. This procedure was necessary to ensure that both the objective and subjective valence of the odour corresponded to the experimental manipulation.

Miscellaneous exclusion criteria. Participants taking medication for depression or anxiety, those with a history of severe motion sickness, and those with extensive experience with immersive VR were excluded outright at recruitment (the latter were excluded due to the risk of their markedly different expectations).

Insert Table 1

Material

The project was carried out in a room (3.75 m X 2.50 m X 2.40 m) with an immersion area of 1.80 m X 2.50 m X 2.40 m. The scent machine was suspended from the ceiling in the middle of the immersion area (its bottom was 2.10 metres from the floor).

The VE consisting of a virtual apartment was generated via Virtools (version 5) by a computer equipped with an Intel Core2 Quad CPU Q9650 (3.00 GHz, 4.00 Go RAM) processor, an Nvidia GeForce GTX 280 graphics card, and the Microsoft Windows XP Professional Version 2002 SP3 operating system. The image was projected in stereoscopy, on a diagonal FOV of 60 degrees, with a resolution of 1280 X 1024 in an NVIS nVisor SX60 HMD. The acoustic element of the environment was generated by Creative's Sound Blaster X-Fi sound card and delivered to the user through headphones integrated in the HMD.

While participants actuated a cordless computer mouse to walk (forward and backward) in the VE, small positional changes (rotations, crouches, shuffles, etc.) relied on their own actual adjustments in body position. The users' movements were captured by six-degrees-of-freedom motion tracking. A precision position tracking (PPT) marker allowed the WorldViz PPT Studio Pro version 3.14.5451 software to situate each user's head via an infrared-emitting diode fixed on top of the HMD. As part of the PPT system, an InterSense InertiaCube3 installed on the HMD provided the orientation of the user's head. The data pertaining to position and orientation was processed by WorldViz's PPT Studio Pro; this application was run by a peripheral server equipped with an Intel 2140 processor (1.6 GHz, 512 Mo RAM). This server was connected to the previously described computer via a dedicated network card and sent tracking data to Virtools via an integrated VRPN7.

To deliver the scents, an SDS100 Scent Palette (Biopac Systems, Inc.) was integrated in the VR system so that each room of the virtual apartment was associated with its own scent chamber (the SDS100 has eight chambers). Each scent cartridge consisted of a small jar filled with a gel-based scent compound. When a user entered a virtual room, and as long as they were in that room, a stream of air was injected into the chamber assigned to that particular room (when no scent was desired, there was no scent cartridge in the corresponding chamber). This air stream was delivered to the SDS100 at a pressure of 20 psi by an Omega compressor (Quality Compressed Air Products). In the scent chamber, the air "scrubbed" the surface of the gel-based scent compound and then escaped the chamber through a one-way rubber valve, and was then dispersed into the room via the four small fans integrated in the SDS100. For this particular experiment, air was injected into the chambers during the first 7 seconds of consecutive 10-second time blocs. The immersion space was designed so that within the time of exposure, the scents would reach participants regardless of their position. Generally, participants tended to be within one metre of the scent machine. The absolute furthest distance a participant could be from the scent machine (head on floor, in the furthest corner of the immersion space) was about 2.50 metres.

It was the ambition of this project to use odours with notably different characteristics. The dimensions primarily used to qualify odours are hedonicity (measure of pleasantness), familiarity, and intensity (Delplanque et al., 2008). Of those, only hedonicity is quantified, not by a continuum but as opposing clusters: pleasant and unpleasant (Schiffman, 1974). Cinnamon apple pie and urine scents were selected respectively for the PLE and UNP groups. These came in the form of two scent cartridges (Biopac Systems, Inc.) named "Grandma's Kitchen" and "Urine."

Overview of the Protocol

Apparent objective of the study. In order to reduce potential bias among the participants, the study's actual objective was not revealed to them prior to immersion. Instead, they were told that each of the rooms of the virtual apartment was deliberately depicted according to various levels of detail (which was incorrect), and that the goal was to determine whether the level of detail impacted the senses of Presence, Reality, and Realism.

Pre-immersion procedure. Once they had read and signed the consent form, participants completed several questionnaires and took cognizance of the pre-immersion instructions. This document (a) reiterated the (false) objective of the study; (b) explained the senses of Presence and Reality, as well as the phenomena of cybersickness; and (c) detailed the scenario associated with the immersion. While the pre-immersion instructions mentioned that participants would be exposed to suspense-type soundtracks, the potential exposure to olfactory stimuli was not revealed. The instructions also detailed how to move around and how to reduce the risk of cybersickness in the VE. Participants were then immersed in the VE. Various subjective measures were taken throughout the immersion, which lasted approximately 15 minutes.

Description of the immersion. According to the scenario presented in the pre-immersion instructions, participants were members of a security team searching for a knife that had been used in a murder. They had to search for the weapon in the bathroom, the living room, the home office, the bedroom, and the kitchen. In an attempt to raise the level of stress, participants were (a) informed that the whereabouts of the killer were still unknown; and (b) exposed to suspense-type soundtracks in each room. In fact, there was no virtual knife in any of the rooms.

When immersed, participants found themselves in an entrance hall outside the apartment. There they were given some time to adjust to the VE and practise moving around. Once participants confirmed being ready to start the experiment, a series of pre-recorded instructions (a) invited them to explore the entrance hall; (b) reminded them of the scenario; (c) invited them to enter the apartment; and (d) gave them directions to help them get to the first room, the bathroom. Once in the bathroom, participants were given one minute to search for the knife, after which a pre-recorded instruction requested that they verbally rate their levels of Presence and Reality (the order of the measures was inversed between each room). Once these measures were taken, another pre-recorded instruction directed participants to the next room, where the procedure was repeated.

Up to the kitchen (see Fig. 1), none of the three groups was exposed to an olfactory stimulus other than the ambient air. In the kitchen, during the one-minute search for the knife, the AMB group (control group) was exposed to the ambient air of the laboratory, the PLE group was exposed to a cinnamon apple pie-like odour ("Grandma's Kitchen" by Enviroscent), and the UNP group was exposed to a urine-like odour ("Urine" by Enviroscent). The kitchen was devoid of any obvious visual cues that could have linked it to either of the olfactory stimuli (see Fig. 2). The immersion was terminated when the two verbal measures were taken in the kitchen.

Insert Figure 1

Insert Figure 2

Post-immersion procedure. After the immersion, participants filled out several questionnaires. The PLE and UNP participants were re-exposed, this time *in vivo*, to the olfactory stimulus that they had been exposed to *in virtuo* (see Fig. 3). The primary goal of this procedure was to confirm, via a questionnaire, that the odour was indeed pleasant to the PLE group, and unpleasant to the UNP group. At the end of the experimental protocol, each participant was administered an olfactory test.

In the debriefing, participants were informed of the actual goal of the study, the details of the protocol were explained, their questions were answered, and they were asked to sign a second consent form authorizing the use of the data collected despite the deception.

In order to reduce the risk of odour contamination from one immersion to the next, at least 45 minutes separated the end of an immersion and the arrival of the next participant. During this period of time, the room was thoroughly ventilated using a fan. Furthermore, on immersion days, the researcher refrained from using scented products (aftershave, scented soap, etc.).

Insert Figure 3

Instruments

General information measures.

Randot[R] Stereotest (Stereo Optical Company, Inc.; www.stereooptical.com). This test measures the smallest detectable depth difference that can be seen in binocular vision. For the purpose of this project, participants were tested via the 10-item graded circle test covering from 400 to 20 seconds of arc at 16 inches (400, 200, 140, 100, 70, 50, 40, 30, 25, and 20 seconds of arc). As stereoscopic vision is necessary to detect depth during VR immersions, participants unable to detect, at worst, depth differences of 70 seconds of arc were removed from the sample.

***Interpupillary distance*.** This is the distance between the centres of the pupils of the eyes. This measure allows the VR system to laterally adjust the optics of the HMD according to each participant's interpupillary distance. This distance was measured pre-immersion using a Topcon PD-5 pupilometer (Topcon Medical Systems, www.topconmedical.com), and the information was entered into the VR software.

***Sociodemographic questionnaire*.** This questionnaire consists of 16 items and collects a number of sociodemographic variables (e.g., age, gender, level of education). As the groups were gender-balanced, the age variable was the only one to be examined as a potential covariate of Presence; the other variables were used to describe the sample. This questionnaire was administered pre-immersion.

***Quick Smell Identification™ Test (Q-SIT; Sensonics, Inc., Haddon Heights, NJ)*.** This is a brief smell test consisting of a 5” X 5.5” card with three scratch-and-sniff stripes. Corresponding to each stripe is a list of four possible specific responses (e.g., lemon, chocolate, strawberry, and pepper), and one “none/other” response. It was used to identify/exclude participants that may have reduced olfactory capabilities. To be included in the sample, participants had to correctly identify at least two of the three odours. Using a score of two as the critical value, negative and positive predictive values are, respectively, 93% and 45% to detect anosmia, and 88% and 63% to detect severe microsmia (Jackman & Doty, 2005). The test-retest reliability of this test is .87 (Jackman & Doty, 2005). For the purpose of this study, the Q-SIT offered an appropriate balance of metrics, cost, and time to administer. It was administered at the very end of the protocol.

Quality of experience measures (dependent variables).

***Brief measure of the sense of Presence*.** In each room of the virtual apartment, a pre-recorded audio instruction requested that participants rate the level of Presence they were experiencing (actual instructions are in French): “On a scale of 0% to 100%, to what extent do you feel present, here in the ________?” Bouchard and colleagues (2004) studied the psychometric properties of a single-item measure of Presence. They found a test-retest of .81 ($p < .001$), as well as excellent convergent and divergent coefficients in the expected direction.

As part of the written pre-immersion instructions, participants had been informed that Presence is the feeling of being there, in the particular room of the apartment. The measures taken in the bedroom and the kitchen served as dependent variables.

***Brief measure of the sense of Reality*.** In each room of the virtual apartment, pre-recorded audio instructions requested that participants rate the level of Reality they were experiencing (actual instructions are in French): "On a scale of 0% to 100%, to what extent does your experience here, in the ________, seem real?" As part of the written pre-immersion instructions, participants had been informed that the sense of Reality is the feeling that their experience in the VE is real (not the illusion that it is). The measures taken in the bedroom and kitchen served as dependent variables.

Independent Television Commission Sense of Presence Inventory (ITC-SOPI; Lessiter, Freeman, Keogh, & Davidoff, 2001). A French-language version (translated by the Laboratoire de Cyberpsychologie de l'UQO) of this questionnaire was used. It is composed of three parts: a general information section (not used for this project because it is redundant with the ITQ), a section A, and a section B. In section A, participants respond to statements regarding thoughts and feelings experienced after the immersion. In section B, participants respond to statements regarding thoughts and feelings experienced during the immersion. Together, parts A and B comprise 44 items scored on a scale of 1 to 5 (1 = *strongly disagree*, 5 = *strongly agree*). However, in order to avoid confusing participants, two items were excluded: item 23 was excluded due to the absence of virtual characters, and item 36 was excluded due to the participants' inability to move objects in this particular VE. The questionnaire helps measure four aspects (to be analyzed separately): (a) Spatial Presence (sense of physical placement in the mediated environment, interaction and control over different parts of the environment; 17 items);

(b) Engagement (tendency to feel psychologically involved and to enjoy the content; 13 items); (c) Ecological Validity / Naturalness (tendency to perceive the mediated environment as lifelike or real; 5 items); and (d) Negative Effects (tendency to have adverse physiological reactions; 6 items). The authors of the inventory reported internal consistency coefficients ranging from .94 (Spatial Presence) to .76 (Naturalness). They also found that, across different media, the scores for the factors were correlated. For the purposes of this project, measures were taken specifically in relation to the experience in the kitchen and served as dependent variables. In accordance with the objectives of this project, only the results of the Spatial Presence and Ecological Validity / Naturalness subscales were to be analyzed.

Measures of potential moderators of the human experience in synthetic environments.

Immersive Tendencies Questionnaire (ITQ; Witmer & Singer, 1998). A validated French-Canadian adaptation of this questionnaire was used (Cronbach's Alpha = .78). It consists of 18 items rated on a 7-point scale (0 = *never*; 6 = *often*) providing a total score and 4 subscale scores (Cronbach's alpha = .78): Focus (the ability to concentrate and to ignore distractions, 5 items); Involvement (the feeling of being caught up in stories and movies, 5 items); Emotion (the intensity of the emotions evoked by stimuli such as movies, 4 items); and Play (the frequency of playing video games, 3 items). As some studies have found a significant correlation between Presence ratings and ITQ scores (e.g., Witmer & Singer, 1998), the questionnaire was administered pre-immersion with a view to be used, if applicable, to statistically control for differences between the groups.

Modified Tellegen Absorption Scale (MODTAS; Jamieson, 2005). A French-language version of this questionnaire was used to measure absorption; that is, the openness to absorbing and self-altering experiences (Tellegen & Atkinson, 1974). It consists of 34 statements to which participants indicate the frequency with which each of the statements is true (5-point scale: 0 = *never*, 4 = *very often*). The Cronbach's alpha for the MODTAS is $\alpha = .94$ (Jamieson & Loi, 2013). As some studies have found a significant correlation between Presence ratings and Absorption (e.g., Sas, 2004), the questionnaire was administered pre-immersion with a view to be used, if applicable, to statistically control for differences between the groups.

Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993). A French-Canadian version of this questionnaire was used to measure the level of cybersickness felt by participants (Cronbach's alpha = .86). It consists of 16 items and measures the intensity of various symptoms linked to cybersickness (e.g., general discomfort, fatigue) using a 4-point scale (1 = *not at all*, 4 = *severely*). It was administered both pre- and post-immersion and served to document the side effects of the treatments; post-immersion outlier scores were used to identify participants who should be withdrawn due to an excessive level of cybersickness (which could threaten the validity of the responses to the post-immersion questionnaires).

Measures of olfactory perception.

***In virtuo detection of olfactory stimulus*.** This questionnaire verified whether participants detected an odour in the kitchen. If so, a series of follow-up questions investigated the type of odour (free-text response), its suspected source in the kitchen (free-text response), its concordance with the visual scene (6-point scale: 0 = *extremely discordant*, 5 = *extremely concordant*), its level of pleasantness (6-point scale: 0 = *extremely unpleasant*, 5 = *extremely pleasant*), its intensity (7-point scale: 1 = *very weak intensity*, 7 = *very strong intensity*), and its familiarity (7-point scale: 0 = *not at all familiar*, 6 = *very familiar*). The potential link to an autobiographic event was also investigated (free-text response). The questionnaire's purpose was to (a) ensure participants were assigned to the intended experimental group and (b) collect descriptive data about the perceived olfactory stimulus. “Crossover” participants (those assigned to the PLE group but who rated the odour as unpleasant, and those assigned to the UNP but who rated the odour as pleasant) were withdrawn from the sample.

In vivo detection of olfactory stimulus. This six-item questionnaire was only administered to participants in the PLE and UNP groups. It was completed right after the post-immersion questionnaires. The procedure consisted in seating participants under the scent machine and, for 30 seconds, exposing them to the same olfactory stimulus they were exposed to during the immersion. The questionnaire investigated the type of odour detected (free-text response), its level of pleasantness (6-point scale: 0 = *extremely unpleasant*, 5 = *extremely pleasant*), its concordance with the kitchen (6-point scale: 0 = *extremely discordant*, 5 = *extremely concordant*), its intensity (7-point scale: 1 = *very weak intensity*, 7 = *very strong intensity*), and its familiarity (7-point scale: 0 = *not at all familiar*, 6 = *very familiar*). The potential link to an autobiographic event was also investigated (free-text response). The primary purpose of this procedure was to ensure that the participants who did not report having detected an odour during the immersion were (a) able to detect the odour and (b) assigned to the intended experimental group. “Crossover” participants (those assigned to the PLE group but who rated the odour as unpleasant, and those assigned to the UNP condition but who rated the odour as pleasant) were withdrawn from the sample.

Results

IBM SPSS Statistics 22 was utilized for all statistical analyses. Assumptions were verified prior to each analysis; non-parametric tests were carried out, if applicable.

Analysis of Control Variables and Manipulation Checks

Pre-immersion differences between groups. Multiple one-way ANOVAs confirmed that, in terms of pre-immersion characteristics, the groups did not differ in terms of age, immersive tendencies, and/or absorption tendencies (see Appendix for complete results).

Immersion-induced negative side effects. A one-way ANOVA confirmed that the immersion-induced negative effect differed between the AMB and UNP groups. Due to this difference, and considering that immersion-related significant effects could potentially affect the dependent variables of interest, the potential covariability between this variable and the dependent variables was verified prior to each analysis. No correlation justifying the use of this variable as a covariate was detected (details available on request). A combination of Kruskal-Wallis and Wilcoxon tests confirmed that the groups' level of simulator sickness did not differ (see Appendix for complete results).

Characteristics of olfactory stimuli detected in virtuo. The detection rates of the PLE and UNP odours were, respectively, 15% and 60%. For the characteristics of the PLE and AMB odours and a comparison of the characteristics of the PLE and UNP odours, see Appendix.

Characteristics of olfactory stimuli detected in vivo. For detection rates, characteristics of the PLE and AMB odours, and a comparison of the characteristics of the PLE and UNP odours, see Appendix.

Analysis of Dependent Variables

The sense of Presence.

Brief measure of Presence. The effect on Presence of exposure to odours was verified via a three-(AMB, PLE, UNP)-by-two (bedroom-control, kitchen-experimental) planned contrasts interaction for repeated-measures designs. The a priori contrast revealed that, in terms of Condition, there was no statistically significant difference in Presence either between AMB and PLE (t = .07; p = .94; η^2 = .00) or between AMB and UNP (t = -.09; p = .93; η^2 = .00). Furthermore, there was no statistically significant Time effect on Presence (t = 1.52; p = .13; η^2 = .04). When examined for each group individually, the pre-post difference was found to be statistically significant only for the UNP group (t = -2.13; p = .046; η^2 = .19). Finally, while there was a statistically significant Interaction effect between AMB and UNP (t = 2.07; p = .04; η^2 = .07), there was none between AMB and PLE (t = 1.06; p = .29; η^2 = .02). Mean values and standard deviations are shown in Table 2, and an illustration of the interaction is shown in Fig. 4.

Insert Table 2

Insert Figure 4

Spatial Presence subscale of the ITC-SOPI. The effect of the exposure to odours on Spatial Presence was verified via planned comparisons. The first contrast revealed that the degree of Spatial Presence was statistically significantly higher for the UNP group (M = 3.39, SD = .44) than for the AMB group (M = 2.95, SD = .60; t = -2.64, p = .01, d = .84). The second contrast showed no statistically significant difference in Spatial Presence between the PLE and AMB groups (t = -1.86, p = .07, d = .56). Mean values and standard errors are shown in Fig. 7.

Insert Figure 5

Relationship between Presence and characteristics of the odours. To investigate how the individual dimensions of the odours might have affected the sense of Presence, correlations between Presence and each characteristic of the perceived odours were calculated. To this end, using the brief measures of Presence in the bedroom and in the kitchen, Presence residual gain scores were calculated (see Manning & Dubois, 1962; Tracy & Rankin, 1967). The results of the correlations (Pearson or Spearman) are presented in Table 3.

Insert Table 3

The sense of Reality.

Brief measure of Reality. The effect of exposure to odours on the sense of Reality was verified via a three-(AMB, PLE, UNP)-by-two (bedroom-control; kitchen-experimental) planned contrasts interaction for repeated-measures designs. The a priori contrast revealed that in terms of Condition, there was no statistically significant difference in the sense of Reality, either between AMB and PLE (t = -.13; p = .90; η^2 = .00) or between AMB and UNP (t = -.62; p = .54; η^2 = .01). There was a statistically significant Time effect on Reality (t = -2.12; p = .04; η^2 = .07). Finally, there was no statistically significant Interaction effect either between AMB and PLE (t = .60; p = .55; η^2 = .01) or between AMB and UNP (t = 1.17; p = .25; η^2 = .02). Mean values and standard deviations are shown in Table 3 and an illustration of the interaction is shown in Fig. 8.

Insert Figure 6

The sense of Realism.

Ecological Validity subscale of the ITC-SOPI. The effect of the exposure to odours on Ecological Validity was verified via planned comparisons. Due to the heterogeneity of the variance, a non-parametric a priori comparison was conducted. The results of Mann-Whitney tests indicated that the Ecological Validity of the AMB experience (Mdn = 3.40) did not vary in a statistically significant manner either from that of the PLE (Mdn = 3.30; U = 175.50, z = -.67, p = .51, r = -.11) or UNP conditions (Mdn = 3.40; U = 178.50, z = -.59, p = .57, r = -.09). Mean values and standard errors are shown in Fig. 9.

Insert Figure 7

Discussion

The research hypothesis of this experiment stated that, even in the absence of evident visual cues that could link the visual scene to a particular odour, exposure to an olfactory stimulus, whether pleasant or unpleasant, would be associated with a statistically significantly higher level of Presence. This hypothesis was partially confirmed.

The low detection rate of the olfactory stimuli (15% for PLE and 60% for UNP) is an interesting phenomenon. However, the reported detection rate may be somewhat underestimated. Indeed, once exposed to the odour a second time (*in vivo*), several participants who had initially reported not having detected an odour in the kitchen, then recalled having perceived the odour in the kitchen (this information was unsolicited and not part of any questionnaire). Interestingly, some participants mentioned that they had wondered whether they had imagined the odour, and one participant in the AMB group reported the detection of an odour in the kitchen. The fact that the participants were unaware of the potential exposure to olfactory stimuli combined with the absence of any obvious sources of odours in the kitchen and the focused attention on the visual task may have contributed to the overall low detection rate. In addition, the dissimilarity in perceived intensity and pleasantness between the odours may have contributed to the difference in detection rates between the PLE and UNP groups. This hypothesis is in line with the findings of Jacob and Wang (2006). In their study, they found that, *in vivo*, (a) reaction time is dependent on the concentration of the odour and (b) it takes more time to detect a pleasant odour than an unpleasant one. The difference in reaction time may be related to the greater significance of unpleasant odours for survival (Jacob & Wang, 2006; e.g., the detection of spoiled food).

Overall, when comparing the characteristics attributed to the PLE and UNP olfactory stimuli, it can be concluded that the odour perceived by the PLE group was more pleasant, less intense, more familiar, and more concordant with the visual scene of the kitchen. The fact that the differences in intensity, familiarity, and concordance with the visual scene did not reach statistical significance *in virtuo* can, at least partially, be attributed to the low number of participants who consciously detected the odour during the immersion (n = 3).

No statistically significant difference was detected in the levels of Presence between the PLE and AMB groups. One factor that may have contributed to this is the very low percentage of participants who seem to have consciously perceived the pleasant odour during the immersion. According to the per-immersion brief repeated measures of Presence, there was a statistically significant Condition X Time interaction effect between the AMB and UNP groups; the size of the effect was small. According to the independent measures of Presence, the results of the ITC-SOPI Spatial Presence subscale indicated that the UNP group’s level of Presence was statistically significantly higher than that of the AMB group; the size of the effect was large. Overall, these results suggest that exposure to the unpleasant odour did have an effect on the level of Presence. However, the inter-instrument variability of the effect size is quite large. One possible contribution to the inter-instrument variability may be related to undetected pre-immersion differences between the groups. Indeed, a great number of user-related variables have been found to potentially affect Presence, and the difficulty controlling these in between-subject design may have contributed to this difference. In addition to the individual variables this experiment controlled for (gender, stereoscopic vision, age, immersive tendencies, absorption tendencies, and olfactory acuity), other individual factors have been found to affect the sense of Presence. These include level of empathy (Nicovich, Boller, & Cornwell, 2005), creative imagination (Heeter, 1992; Lauria, 1997), cognitive abilities (Sacau, Laarni, & Hartmann, 2008), and willingness to be “transported” in a VE and to “accept” the VE as real (Laurel, 1993; Slater & Usoh, 1993; Steuer, 1995). The difficulty in controlling all of these individual variables led to Jones and colleagues’ (2004) recommendation that, in order to better differentiate subjective differences in condition, a within-subject repeated measures design should be utilized. Nevertheless, overall, the results of this study effectively suggest that the level of Presence was affected by exposure to the unpleasant odour. The fact that the less concordant odour had an effect on Presence while the more concordant one did not is also interesting and counterintuitive. Here again, the lower perceived intensity and the low detection rate of the pleasant odour may have played a role.

This experiment grouped the experimental conditions according to one dimension of odours, pleasantness. For the purpose of an experimental design, as well as for the potential application of the results, it is the dimension that can best be controlled. However, in order to complete the picture of how each dimension can impact the sense of Presence, it was deemed useful to calculate the corresponding correlations. Although none of these were statistically significant, it is the level of perceived concordance with the visual scene that correlated highest with the sense of Presence; the effect sizes of this correlation varied between weak and moderate. This result was based on the 15 participants (3 from the PLE group and 12 from the UNP group) who consciously perceived the olfactory stimulus in the VE (out of 40 participants exposed to the stimulus). In the future, it could be interesting to see how this correlation changes in a sample with a higher *in virtuo* detection rate.

Neither exposure to the pleasant or unpleasant odour had a statistically significant effect on the level of Reality felt in the kitchen. It is, however, worthwhile noting that a small statistically significant Time effect was detected. This result suggests that, on average across the three groups, the visual characteristics of the kitchen triggered a higher level of Reality than those of the bedroom.

No statistically significant difference was detected between the level of Realism for the AMB group and either the PLE or UNP groups.

Limitations

Researching the effects of an exposure to olfactory stimuli on Presence entails particular challenges. First, investigating differences in levels of Presence is problematic in itself. To prevent post-immersion biases, rating an experience in a VE should be done while the rater is immersed. However, the simple act of questioning participants on their level of Presence can create a break in Presence and affect the rating (Slater, 2004). It is therefore difficult to envision asking more than a single question pertaining to Presence during immersion.

Working with odours is also associated with particular limitations. The numerous individual factors that can affect Presence call for a repeated-measures design. However, as odours tend to linger, and given that the laboratory was not equipped with a ventilation system that could “flush out” odours during immersion, the odours could only be used in the last room visited (i.e., the order of the repeated measures could not be reversed).

Another limitation pertains to the results regarding the pleasant odour. The experiment examined the effect of exposure to, not the perception of, odours in VR. However, the large difference between the conscious perception rates of the pleasant and unpleasant odours somewhat limits the conclusions that can be drawn regarding exposure to the pleasant odour.

Conclusions and recommendations

The results of this study suggest that, in a VE devoid of obvious visual cues linking an odour to the visual scene, exposure to an unpleasant odour can increase the sense of Presence.

While the study has provided some level of answer to the possible link between exposure to olfactory stimuli and Presence in VR, it also leads to more questions. One of these concerns the role that conscious odour detection plays in the effect of olfactory stimuli on Presence. The fact that the participants were unaware of the use of odours, and their focus on a visual task, may have contributed to the large difference between the pleasant and unpleasant odour detection rates. In turn, the low detection rate of the pleasant odour may explain its lack of effect on Presence. On the other hand, it has been found that even subliminal odours can influence processes such as implicit odour memory (e.g., Köster, Degel, & Pipper, 2002) and social likeability judgements (Li, Moallem, Paller, & Gottfried, 2007). Thus, it remains unclear whether the lack of effect of the pleasant odour is due to the lack of conscious detection or, quite simply, that pleasant odours have no effect on Presence in a VE.

Another question pertains to the role of the visual scene. This particular project aimed to verify the effect of exposure to pleasant and unpleasant odours in a visual environment devoid of obvious cues that could link sight and smell. However, the effect of the interaction between vision and olfaction has been well documented (e.g., Demattè, Sanabria, & Spence, 2009; Ferrier, Streff, Martin, Brouillet, Barkat-Defradas, & Jiménez, 2009; Seigneuric, Durand, Jiang, Baudouin, & Schaal, 2010). Thus, as a potential follow-on project, it may be of interest to investigate how the quality of experience measures would be affected if the protocol was repeated in a virtual kitchen that "looks to smell" like one of the olfactory stimuli. At the same time, such a project might contribute to finding out whether a "visual/olfactory match" can affect the detection rate of olfactory stimuli in VR.

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Table 1

Sociodemographic Description of Participants in the Three Odorant Conditions (N = 60)

Measure	Ambient (AMB) n = 20	Pleasant (PLE) n = 20	Unpleasant (UNP) n = 20
Age	25.50 (9.04)	25.70 (10.71)	26.50 (9.08)
Dominant culture			
African	0%	5%	10%
Asian	0%	5%	15%
European	5%	0%	5%
North American	90%	90%	70%
South American	5%	0%	0%
Highest level of education completed			
Master’s/Ph.D.	15%	5%	5%
Bachelor	25%	5%	30%
Pre-university college	55%	70%	60%
High school	5%	20%	5%

Note. Standard deviations of age are shown in brackets.

Table 2

Brief Measures of Presence and Reality collected in virtuo

Measure	Bedroom (control)		Kitchen (experimental)	
	M (*SD*)	95% CI	*M* (*SD*)	95% CI
Brief Presence				
Ambient	75.00 (12.03)	[69.37, 80.63]	73.75 (2.76)	[67.97, 79.53]
Pleasant	73.10 (16.81)	[65.23, 80.97]	75.00 (17.84)	[66.65, 83.35]
Unpleasant	72.35 (18.08)	[63.89, 80.81]	77.25 (14.73)	[70.36, 84.14]
Brief Reality				
Ambient	70.10 (16.36)	[62.44, 77.76]	71.00 (12.63)	[65.09, 76.91]
Pleasant	69.75 (13.91)	[63.24, 76.26]	72.60 (17.39)	[64.46, 80.74]
Unpleasant	71.20 (18.52)	[62.53, 79.87]	75.90 (17.48)	[67.72, 84.08]

Note. CI = confidence interval.

Table 3

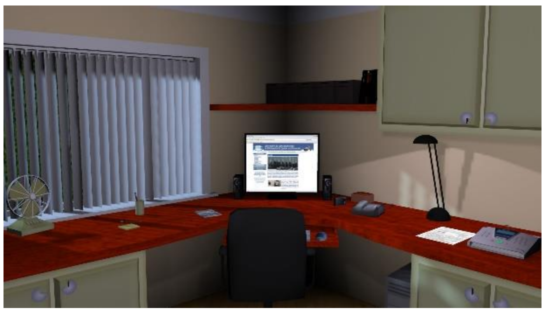
Relationship between Presence and Characteristics of Odours

Measure	Concordance	Pleasantness	Intensity	Familiarity
Change in Presence	.39	-.20	.00	.11
ITC Spatial Presence	.26	-.10	.22	.11

Note. Correlations are based on the PLE and UNP participants who detected an odour *in virtuo* (PLE = 3; UNP = 12).
* $p < .05$.

a. Bathroom layout

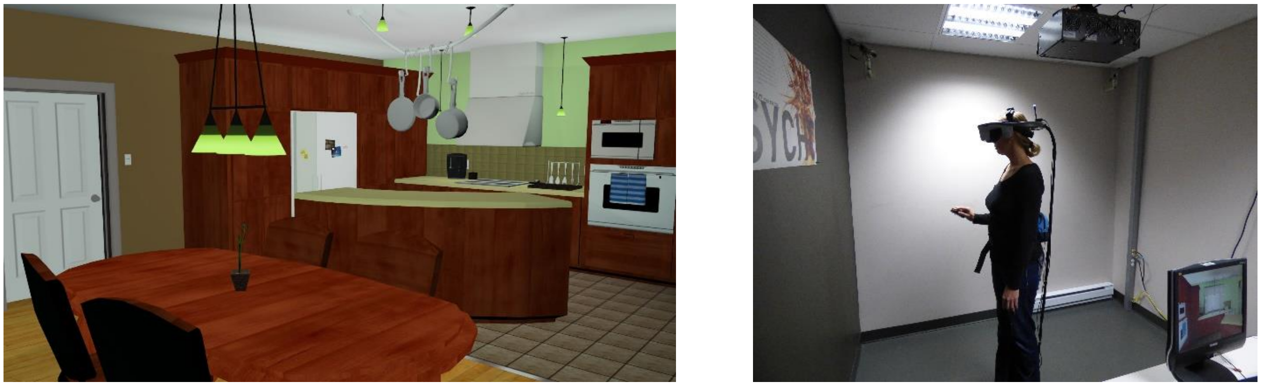
b. Living room layout



c. Office layout

d. Bedroom layout

Figure 1. Virtual rooms visited prior to the virtual kitchen.



a. Kitchen layout b. Participant in immersion

Figure 2. Virtual kitchen and immersion room.
Note. For illustrative purposes, the participant in immersion is shown with the lights on; during the actual protocol, the immersion room lights were turned off. In Fig. 2a., the scent delivery system can be seen hanging from the ceiling, in the centre of the immersion space.

Figure 3. Post-immersion evaluation of olfactory stimulus. For 30 seconds, participants were exposed, this time *in vivo*, to the stimulus to which they had been exposed in the virtual kitchen.

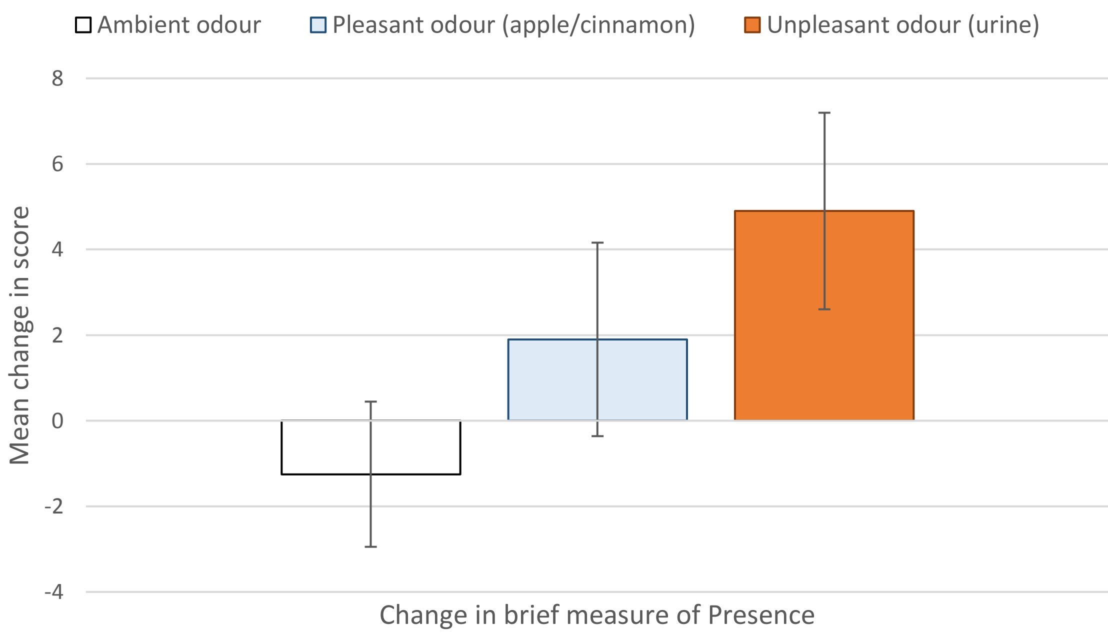


Figure 4. Illustration of the brief measure of Presence X Time interaction effect, as shown by the mean change from the control to the experimental condition. Standard errors are represented in the figure by the error bars attached to each column.

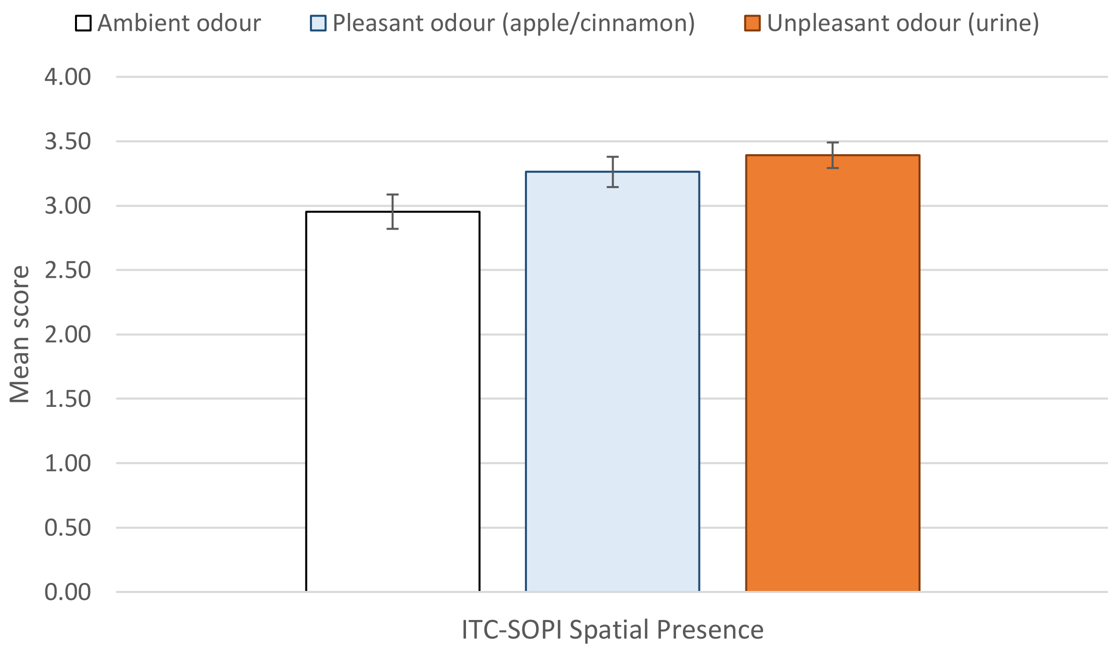


Figure 5. The sense of Presence (as measured by the ITC-SOPI Spatial Presence subscale).

Standard errors are represented in the figure by the error bars attached to each column.

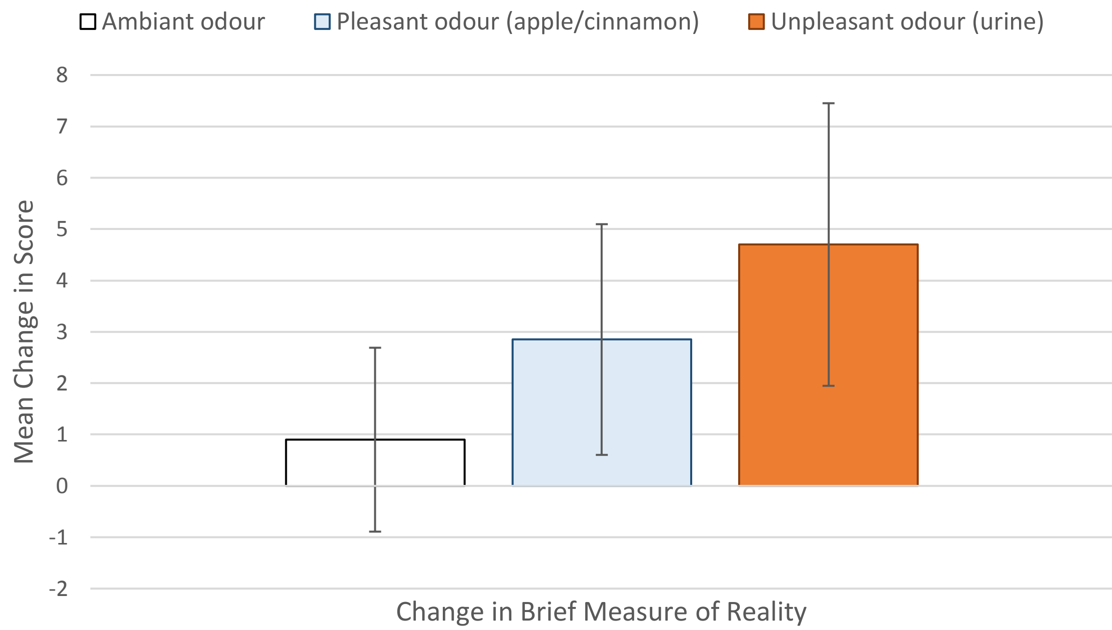


Figure 6. Illustration of the brief measure of Reality X Time interaction effect, as shown by the mean change from the control to the experimental condition. Standard errors are represented in the figure by the error bars attached to each column.

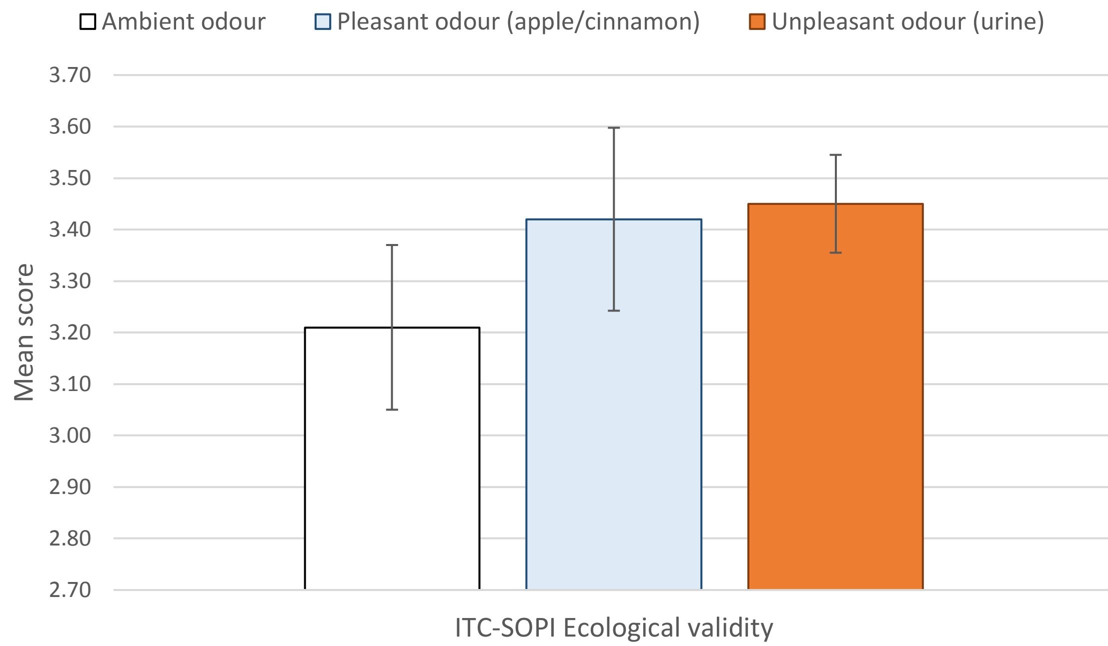


Figure 7. The sense of Realism (as measured by the ITC-SOPI Ecological Validity subscale). Standard errors are represented in the figure by the error bars attached to each column.

Appendix

Additional Analyses

Pre-Immersion Differences Between Groups

Multiple one-way ANOVAs verified whether the groups differed in terms of pre-immersion characteristics such as (a) age, (b) immersive tendencies, and/or (c) absorption tendencies.

Age. Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that the age of the participants in the AMB (M = 25.50; SD = 9.04; Mdn = 23.00), PLE (M = 25.70; SD = 10.71; Mdn = 21.00), and UNP (M = 26.50; SD = 9.08; Mdn = 22.50) groups did not differ in a statistically significant manner ($H(2) = .86$, $p = .65$).

Tendency to be immersed. The results of the one-way ANOVA confirmed that the tendency to be immersed did not differ between the AMB, PLE, and UNP groups (respectively M = 56.20, SD = 11.74; M = 55.15, SD = 8.90; M = 51.85, SD = 12.27; $F(2, 57) = .84$, $p = .44$, $\eta_p^2 = .03$).

Tendency to be absorbed. The results of the one-way ANOVA confirmed that the tendency to be absorbed did not differ between the AMB, PLE, and UNP groups (respectively M = 1.74, SD = .52; M = 1.64, SD = .39; M = 1.74, SD = .15; $F(2, 57) = .21$, $p = .81$, $\eta_p^2 = .01$).

Immersion Induced Negative Side Effects

ITC-SOPI. The results of the one-way ANOVA suggested that the level of immersion-induced negative side effects for the AMB (*M* = 1.94, *SD* = .81), PLE (*M* = 2.12, *SD* = .79), and UNP (*M* = 2.78, *SD* = .95) groups differed in a statistically significant manner ($F(2, 57) = 5.44$, $p = .01$, $\eta_p^2 = .16$). The results of a post hoc Tukey test suggested that only the AMB and UNP groups differed ($p = .01$).

Simulator Sickness Questionnaire. In order to verify the effect of the odours on cybersickness, planned contrasts interaction for repeated-measures designs were used; in this case, there were three conditions (AMB, PLE, UNP) by two times (pre-immersion, post-immersion). Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that pre-immersion cybersickness levels for the AMB (*M* = .23; *SD* = .17; *Mdn* = .22), PLE (*M* = .27; *SD* = .23; *Mdn* = .23), and UNP (*M* = .24; *SD* = .21; *Mdn* = .16) groups did not differ in a statistically significant manner ($H(2) = .60$, $p = .74$), nor did they post-immersion (AMB: *M* = .28; *SD* = .24; *Mdn* = .19; PLE: *M* = .33; *SD* = .24; *Mdn* = .31; UNP: *M* = .39; *SD* = .28; *Mdn* = .34) ($H(2) = 1.91$, $p = .39$). Within groups, Wilcoxon tests detected no difference between pre- and post-immersion cybersickness, either for AMB ($z = -1.09$, $p = .28$, $r = -.17$), PLE ($z = -1.49$, $p = .14$, $r = -.24$), or UNP ($z = -1.76$, $p = .08$, $r = -.28$).

Characteristics of Olfactory Stimuli Detected In Virtuo

AMB group. For this group, although no olfactory stimulus was generated, the *in virtuo* detection rate of an olfactory stimulus in the virtual kitchen was 5% (1 out of 20). More specifically, this male participant reported that the odour was associated with a memory and rated the odour as follows: pleasantness = 2.00, intensity = 4.00, familiarity = 3.00, and concordance with the kitchen = 1.00.

PLE and UNP groups. Detection rates, rate of association with a memory, and presumed source of odours are shown in Table A.

Table A

Detection, Association with Memory, and Source of Odours Detected In Virtuo

Measure	Pleasant odour (cinnamon apple pie)	Unpleasant odour (urine)
Detection rate		
All participants within condition	15%	60%
Males within condition	12.50%	50%
Females within condition	16.67%	66.67%
Rate of association with memory	33%	58.33%
Participants' presumed source of odour		
Element of VE	33.33%	16.67%
Element of physical world	66.67%	16.67%
Imaginary source	0%	41.67%
Unknown	0%	25%

Comparison between the characteristics of the PLE and UNP odours. Due to the size disparity between the groups and in order to compare the characteristics of the PLE and UNP odours, non-parametric comparisons were conducted. These confirmed that, as assessed by the PLE (n = 3) and UNP (n = 12) participants who detected the odour *in virtuo*, the UNP odour was statistically significantly more unpleasant (*Mdn* = 4.00) than the PLE odour (*Mdn* = 1.00; $U = 0.00$, $z = -2.68$, $p = .01$, $d = 4.64$, $r = -.92$). However, the differences between the PLE and UNP odours were not statistically significant either in terms of intensity (respectively *Mdns* = 5.00 and 5.50; $U = 7.50$, $z = -1.66$, $p = .10$, $d = 1.19$, $r = .51$), familiarity (respectively *Mdns* = 4.00 and 2.50; $U = 6.50$, $z = -1.71$, $p = .09$, $d = -1.11$, $r = -.49$), or concordance with the visual scene (respectively *Mdns* = 3.00 and 2.00; $U = 12.50$, $z = -.82$, $p = .41$, $d = -.58$, $r = -.58$). Mean values and standard errors are shown in Fig. A.

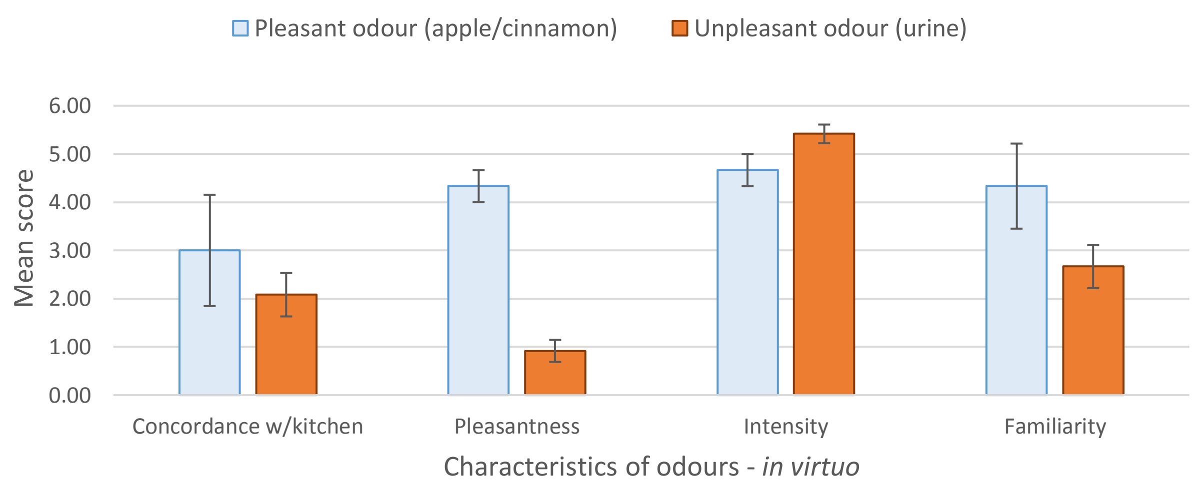


Figure A. Characteristics of olfactory stimuli detected *in virtuo*. These are based on the participants who reported having detected an odour in the kitchen (for the pleasant odour, $n = 3$; for the unpleasant odour, $n = 12$). Standard errors are represented in the figure by the error bars attached to each column.

Characteristics of Olfactory Stimuli Detected In Vivo

PLE group. The post-experiment *in vivo* detection rate of the same olfactory stimulus these participants had been exposed to in the kitchen was 100% (20 out of 20). Fifteen of the group's members (75%) stated that the odour was associated with a memory.

UNP group. The post-experiment *in vivo* detection rate of the same olfactory stimulus these participants had been exposed to in the kitchen was 100% (20 out of 20). Eighteen of the group's members (90%) stated that the odour was associated with a memory.

Comparison between the characteristics of the PLE and UNP odours. Due to the non-normal distribution of the characteristics of the odours, and in order to compare the characteristics of the PLE and UNP odours, non-parametric comparisons were conducted. These confirmed that, as assessed by the participants in the PLE (n = 20) and UNP (n = 20) groups when exposed to the odour *in vivo* (post-questionnaires), the UNP odour was statistically significantly less pleasant (Mdn = 0.00) than the PLE odour (Mdn = 4.00; U = 0.00, z = -5.54, p = .00, d = 4.42, r = .91), more intense than the PLE odour (respectively, $Mdns$ = 6.00 and 5.00; U = 122.50, z = -2.20, p = .03, d = -.82, r = -.38), less familiar than the PLE odour (respectively, $Mdns$ = 3.50 and 5.00; U = 113.00, z = -2.43, p = .02, d = .93, r = .42), and less concordant with the visual scene than the PLE odour (respectively, $Mdns$ = 1.00 and 3.00; U = 121.00, z = -2.19, p = .03, d = .74, r = .35). Mean values and standard errors are shown in Fig. B.

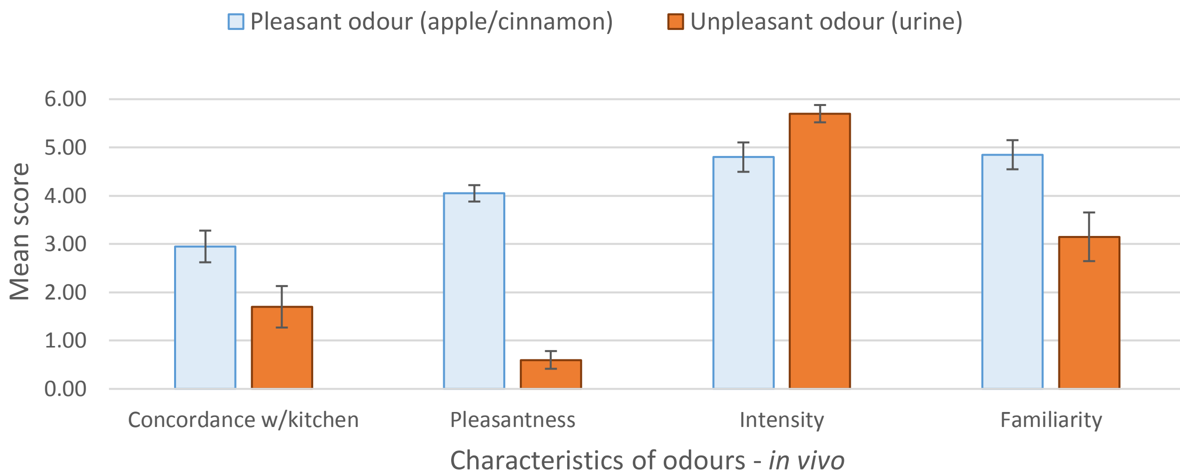


Figure B. Characteristics of olfactory stimuli detected *in vivo*. These are based on a 30-second exposure to the same stimulus the participants had been exposed to *in virtuo*. This time, however, participants had been made aware of the exposure to an olfactory stimulus beforehand (*n* = 20 for each of the groups). Standard errors are represented in the figure by the error bars attached to each column.

Article 3

In a Dirty Virtual Room.

Exposure to an Unpleasant Odour Increases

the Senses of Presence, Reality, and Realism

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Abstract

A recent study found that in a virtual room devoid of obvious visual cues linking visual and olfactory stimuli, exposure to an unpleasant odour (but not to a pleasant one) led to statistically significant increases in the sense of Presence. It also reported that neither exposure to an unpleasant or pleasant odour had an effect on the senses of Reality or Realism. The goal of this project was to re-examine these relationships in a virtual environment (VE) where the visual scene was linked to an unpleasant odour (i.e., a virtual room that "looks to smell bad"). To this end, three groups of randomly assigned participants (13 females and 7 males), unaware of the potential exposure to an olfactory stimulus, were immersed in a filthy virtual kitchen. Depending on their experimental condition, they were exposed to either the ambient odour in the laboratory, a pleasant odour, or an unpleasant odour. The results revealed that exposure to the unpleasant odour increased the senses of Presence, Reality, and Realism in a statistically significant matter. Furthermore, the results regarding odour detection rates suggest that visual/olfactory concordance may have facilitated the detection of the unpleasant odour. Overall, the results suggest that, in the case of an unpleasant odour, visual/olfactory concordance can notably enrich the quality of the user experience in virtual reality (VR).

Keywords: virtual reality, presence, olfaction, odours, reality, realism

In a Dirty Virtual Room.

Exposure to an Unpleasant Odour Increases the Senses of Presence, Reality, and Realism

Introduction

The potential benefits of integrating olfactory stimuli in virtual reality (VR) have been outlined by various authors (e.g., Baus & Bouchard, 2010; Ischer et al., 2014). However, despite a consensus surrounding the potentially positive effect of taking VR beyond sight, sound, and touch, empirical studies examining the effects of olfactory stimuli on the quality of the user experience are scarce.

Quantifying the potential benefits of integrating olfactory cues in VR can be accomplished via a variety of concepts, including the senses of Reality, Realism, and Presence. While the sense of Reality is defined as the degree to which the user perceives the immersion as real (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000), the sense of Realism is defined as the similarity between the synthetic and the corresponding non-synthetic stimuli (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000). Although the exact definition of the sense of Presence varies depending on the author, Heeter's (1992) definition stating that the term refers to the impression of being in the virtual environment (VE) was adopted here.

A number of individual (user-related) and environmental (system-related) variables have been found to affect Presence. Because it is difficult to influence individual factors, these are more of theoretical interest. Environmental factors, however, can be readily manipulated, and accordingly are of particular interest to VR developers. Broadly speaking, environmental factors can be subcategorized as ergonomics-related variables (e.g., comfort of the equipment; Billinghurst & Weghorst, 1995), interactivity-related variables (e.g., update of the visual scene in accordance with user movement; Hendrix & Barfield, 1996a), and variables related to the quality of the stimuli (e.g., level of realism of the visual elements; Waterworth & Waterworth 2003). It has also been suggested that an increase in the number of stimulated senses can lead to higher levels of Presence. More specifically, it has been reported that exposure to sound (Dinh, Walker, Song, Kobayashi, & Hodges, 1999), spatialized sound (Hendrix & Barfield, 1996a,b), and the use of tactile augmentation (Dinh, Walker, Song, Kobayashi, & Hodges, 1999; Hendrix & Barfield, 1996a; Hoffman et al., 1996; Meehan, Insko, Whitton, & Brooks, 2002) can increase the sense of Presence. In addition, mobilization of the body (Slater & Steed, 2000; Slater, Steed, McCarthy, & Maringelli, 1998) and reduced dissociation between proprioception and the senses seem to have a positive influence on the sense of Presence. For example, a user who physically walks on the spot while actuating a joy stick to virtually walk around in a VE can experience a higher level of Presence than one who simply actuates a joy stick to virtually walk around in a VE (Slater, Usoh, & Steed, 1995; Usoh et al, 1999). On the basis that engaging a greater number of a user's senses increases their sense of Presence, it would be expected that exposure to olfactory stimuli will also increase the sense of Presence in VR.

Surprisingly, few authors have published results relating to the potential effect of olfactory cues on Presence in VR. Of these, Dinh and colleagues (Dinh, Walker, Song, Kobayashi, & Hodges, 1999) completed an ambitious project examining the effects of tactile, olfactory, audio, and visual sensory cues on the sense of Presence. To this end, they randomly assigned 322 participants to 16 experimental conditions. After eliminating some of the participants, a minimum of 15 complete data sets per condition were analyzed. During the immersion, which lasted about five minutes, participants were made to tour office spaces and evaluate whether the VR system could potentially be used by real estate brokers to help customers evaluate which office they would want to rent and/or visit *in vivo*. Participants were able to control only their head movements and were moved from room to room and to two different locations within each of the five virtual rooms by the experimenter. The effect of the olfactory stimulus on Presence was investigated via exposure/non-exposure to a coffee smell near the coffee pot in the reception area. To facilitate the delivery of the scent, all participants wore a small oxygen mask connected to a canister of coffee grounds and a small pump. All participants were informed that they may be exposed to odours. Presence was measured via a 100-point rating scale and a 13-item questionnaire. The analyses revealed that exposure to the odour did produce higher scores, but that the differences were not statistically significant.

Considering the important role played by the sense of smell in everyday life (e.g., Baus & Bouchard, 2010), Dinh and colleagues' (Dinh et al., 1999) somewhat counterintuitive results motivated Baus and Bouchard (2016) to re-examine the issue. In a study examining the effects of exposure to olfactory stimuli on the senses of Presence, Reality, and Realism, they devised a protocol intended to improve on Dinh and colleagues' (1999) methodology. The principal methodological differences included (a) non-disclosure of the actual objective of the experiment; (b) non-disclosure of the potential exposure to an olfactory stimulus; (c) control of potential covariates of Presence; (d) use of a pleasant odour condition, an unpleasant odour condition, and a control condition; (e) measurement of the odours' dimensions; and (f) verification of each participant's olfactory function. The immersion scenario had participants search a virtual apartment for a knife used in a murder (in reality, there was no such knife). After a period of accommodation in the entrance hall outside the apartment, the participants entered the apartment and then proceeded from the bathroom to the living room, home office, bedroom, and kitchen. The kitchen was the only room where the participants in the experimental conditions were exposed either to a pleasant or an unpleasant odour. In each room, they had one minute to search for the knife, after which brief measures of Presence and Reality were taken. Once these measures were taken in the kitchen, the immersion was terminated, and the participants completed a series of questionnaires. Finally, the participants were informed of the actual objective of the experiment and given the opportunity to disallow the use of the data collected.

The results of the study suggested that exposure to the unpleasant odour, but not to the pleasant one, had a statistically significant effect on the sense of Presence (as measured per-immersion by repeated brief measures, and post-immersion by questionnaire). However, exposure to neither odour had an effect on the senses of Reality or Realism. Interestingly, *in virtuo* conscious detection rates of the olfactory stimuli for the pleasant and unpleasant odours were as low as 15% and 60%, respectively. The authors suggested that the low conscious detection rate of the pleasant stimulus may have contributed to its lack of effect on Presence. In their experiment, Baus and Bouchard (2016) deliberately used a visual scene devoid of objects that could be the obvious source of the experimental odours. One of the interrogations formulated by the authors in their conclusion regarded the effect that a visual/olfactory-concordant environment might have on the sense of Presence.

It was the primary objective of this project to address this question. Exploratory analyses were also conducted to examine whether exposure to a visual/olfactory-concordant VE would be associated with higher levels of Reality and Realism. Lastly, it was of interest how, compared to the results obtained by Baus and Bouchard (2016), the detection rates of the unpleasant odour would be affected by the high level of concordance with the visual scene.

The research hypothesis for this experiment stated that, in a VE that includes visual elements normally associated with an unpleasant smell, exposure to an unpleasant odour would be associated with a statistically significantly higher level of Presence.

Method

General

In order to allow for inter-experiment comparisons, this study followed the protocol used by Baus and Bouchard (2016), except for the following points: (a) while Baus and Bouchard's (2016) virtual kitchen was devoid of objects that could be the obvious source of the experimental odours, the virtual kitchen used in this latest experiment was filled with a group of items normally associated with an unpleasant smell; and (b) an *in vivo* test measuring the detection time for each of experimental odours was added.

Participants

The 60 participants (21 males and 39 females) were recruited on local university and college campuses via adverts and class visits. The inclusion and exclusion criteria were identical to those used by Baus and Bouchard (2016). The group mean ages, dominant cultural influence (by continent), and highest level of education completed are shown in Table 1.

Insert Table 1

Material

The material included a Virtools (version 5)-generated VE, an NVIS nVisor SX60 HMD head-mounted display, an InterSense InertiaCube3, a six-degrees-of-freedom tracking system, an SDS100 Scent Palette (Biopac Systems, Inc.), and two scent cartridges (Biopac Systems, Inc.). For a detailed description, see Baus and Bouchard (2016). The VE (see Fig. 1) was identical to that used by Baus and Bouchard (2016) except that, in this case, the virtual kitchen was very untidy and dirty (see Fig. 2).

Insert Figure 1

Insert Figure 2

Overview of the the Protocol

The protocol was identical to that followed by Baus and Bouchard (2016) with the following exception: during *in vivo* re-exposure to the olfactory stimulus (see Fig. 3), the time required by the participants to detect the odour was measured (see *Instruments* section, *Measures of olfactory perception* subsection).

Insert Figure 3

Instruments

General information measures. The Randot^{R} Stereotest (Stereo Optical Company, Inc.; www.stereooptical.com) was used to ensure that participants could detect, at worst, a depth difference of 70 seconds of arc. The participants' interpupillary distance was measured using a Topcon PD-5 pupilometer (Topcon Medical Systems, www.topconmedical.com), and the Quick Smell Identification^{TM} Test (Q-SIT; Sensonics, Inc., Haddon Heights, NJ) was used to verify that the participants could, at worst, identify two of the three test odours. Sociodemographic variables were collected via a questionnaire. A fuller description of these instruments can be found in Baus and Bouchard (2016).

Quality of experience measures (dependent variables). The sense of Presence was measured, per-immersion, via a brief verbal measure, and post-immersion via the Spatial Presence subscale of the Independent Television Commission Sense of Presence Inventory (ITC-SOPI; Lessiter, Freeman, Keogh, & Davidoff, 2001). While the sense of Reality was measured per-immersion using a brief verbal measure, the sense of Realism was measured post-immersion using the Ecological Validity / Naturalness subscale of the ITC-SOPI (Lessiter, Freeman, Keogh, & Davidoff, 2001). A fuller description of these instruments can be found in Baus and Bouchard (2016).

Measures of potential moderators of the human experience in synthetic environments. Several measures were taken to potentially control for individual differences that can affect the level of Presence. The Immersive Tendencies Questionnaire (ITQ; Witmer & Singer, 1998) measured the ease by which the participants could be immersed in a VE. The Modified Tellegen Absorption Scale (MODTAS; Jamieson, 2005) measured the ease by which the participants could feel absorbed. The Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993) and the Negative Effects subscale of the ITC-SOPI (Lessiter, Freeman, Keogh, & Davidoff, 2001) measured the participants' level of immersion-related discomfort. A fuller description of these instruments can be found in Baus and Bouchard (2016).

Measures of olfactory perception. The *in virtuo* detection of olfactory stimulus questionnaire was administered post-immersion to all participants. Its function was to verify whether an odour had been detected *in virtuo*, and if so, to collect the perceived characteristics of that odour. The *in vivo* detection of olfactory stimulus questionnaire was administered only to the participants of the PLE and UNP groups, once all other questionnaires had been completed. It consisted of a 30-second *in vivo* re-exposure to the olfactory stimulus and aimed to verify the characteristics of the odour, as perceived in the non-synthetic world. A fuller description of these instruments can be found in Baus and Bouchard (2016). In addition to these measures, during the *in vivo* exposure to the olfactory stimulus, the time elapsed between the start of the exposure and the participant's detection of the olfactory stimulus was also measured.

Results

IBM SPSS Statistics 22 was employed for all statistical analyses. Assumptions were verified prior to each analysis and non-parametric tests were carried out, if applicable.

Analysis of Control Variables and Manipulation Checks

Pre-immersion differences between groups. The Kruskal-Wallis test and multiple one-way ANOVAs revealed that the groups did not differ in terms of age, immersive tendencies, or absorption tendencies (for complete results, see Appendix).

Immersion-induced negative side effects. A combination of the Kruskal-Wallis and Wilcoxon tests confirmed that the groups did not differ in terms of immersion-induced negative effects (for complete results, see Appendix).

Characteristics of olfactory stimuli detected in virtuo. The detection rates of the PLE and UNP odours were, respectively, 35% and 95%. The characteristics of the PLE and UNP odours and a comparative analysis of these are presented in the Appendix.

Characteristics of olfactory stimuli detected in vivo. A t-test confirmed that there was no statistically significant difference between the number of seconds required to detect the pleasant (M = 5.03, $S.D.$ = 1.72) and unpleasant odours (M = 4.40, $S.D.$ = 1.46; t = 1.23, p = .23). The detection rates and characteristics of the PLE and UNP odours, as well as a comparison of these characteristics, can be found in the Appendix.

Analysis of Dependent Variables

The sense of Presence.

Brief measure of Presence. In order to verify the effect of the exposure to odours on Spatial Presence, planned contrasts interaction for repeated-measures designs were used; in this case involving three conditions (AMB, PLE, UNP) by two times (bedroom-control, kitchen-experimental). The *a priori* contrast revealed that in terms of Condition, there was no statistically significant difference in Presence either between AMB and PLE (t = .79; p = .43; η^2 = .01), or AMB and UNP (t = -.22; p = .83; η^2 = .00). There was a statistically significant Time effect on Presence (t = -2.88; p = .01; η^2 = .13), but when examined for each group individually, the pre-post difference was found to be statistically significant only for the UNP group (z = -3.35, p = .00, r = -.53). Finally, while there was a statistically significant Interaction effect between AMB and UNP (t = 2.51; p = .01; η^2 = .10), there was none between AMB and PLE (t = .60; p = .55; η^2 = .01). As Presence was not normally distributed for the PLE and UNP groups, these results were confirmed through a combination of Mann-Whitney and Wilcoxon tests. Mean values and standard deviations are shown in Table 2, and an illustration of the interaction is shown in Fig. 4.

Insert Table 2

Insert Figure 4

Spatial Presence subscale of the ITC-SOPI. In order to verify the effect of the exposure to odours on Spatial Presence, planned comparisons were used. The contrasts revealed that neither the level of Spatial Presence of the UNP group (M = 3.46, SD = .60; t = .70, p = .49, d = -1.04, r = -.46) nor that of the PLE group (M = 3.16, SD = .69; t = -.73, p = .47, d = 1.01, r = .45) differed in a statistically significant manner from the level of Spatial Presence of the AMB group (M = 3.31, SD = .66). Mean values and standard errors are shown in Fig. 5.

Insert Figure 5

Relationship between Presence and the characteristics of the odours. In order to verify how the individual characteristics of an odour perceived *in virtuo* may have affected the sense of Presence, correlations were calculated. To measure change in Presence, Presence residual gain scores were calculated (see Manning & Dubois, 1962; Tracy & Rankin, 1967) using the brief measures of Presence in the bedroom and in the kitchen. The results of the Spearman correlations are shown in Table 3.

Insert Table 3

The sense of Reality.

Brief measure of Reality. The *a priori* contrast revealed that in terms of Condition, there was no statistically significant difference in Reality, either between AMB and PLE (t = 1.97; p = .05; η^2 = .06) or between AMB and UNP (t = -.60; p = .55; η^2 = .01). The Time effect on Reality was statistically significant (t = -2.15; p = .04; η^2 = .07). Finally, there was a statistically significant Interaction effect between AMB and UNP (t = 2.62; p = .01; η^2 = .11) but not between AMB and PLE (t = .65; p = .52; η^2 = .01). However, the sense of Reality measures were not normally distributed in either the bedroom or the kitchen, and variances in those two rooms were uneven. Thus, these results were confirmed through a combination of Mann-Whitney and Wilcoxon tests. Mean values and standard deviations are shown in Table 2, and an illustration of the interaction is presented in Fig. 6.

Insert Figure 6

The sense of Realism.

Ecological Validity subscale ITC-SOPI. In order to verify the effect of the exposure to odours on Ecological Validity, planned comparisons were used. The first contrast revealed that the Realism experienced was statistically significantly higher for participants in the UNP condition (M = 3.71, SD = .69) than the AMB condition (M = 3.17, SD = .77; t = 2.17, p = .03, d = 3.35, r = .86). The second contrast showed no statistically significant difference between the Realism of the exposure to the PLE (M = 3.07, SD = .89) and AMB groups (M = 3.17, SD = .77; t = -.40, p = .70, d = -.55, r = -.27). Mean values and standard errors are shown in Fig. 7.

Insert Figure 7

Discussion

The research hypothesis for this experiment stated that, in a VE that includes visual elements normally associated with an unpleasant smell, the exposure to an unpleasant odour would be associated with a statistically significantly higher level of Presence. This hypothesis was partially confirmed.

As also reported by Baus and Bouchard (2016), there were important differences between the *in virtuo* conscious detection rates of the pleasant and unpleasant odours (35% for PLE and 95% for UNP). Interestingly, during the *in vivo* test, when the participants were informed of the impending exposure to an odour, there was no statistically significant difference between the times to detect these odours. A comparison of the PLE and UNP detection rates reported by Baus and Bouchard (2016) revealed that, in this project where the visual scene was loaded with potentially odorous objects, the *in virtuo* conscious detection rates were notably higher for both the PLE (35% versus 15%) and UNP (95% versus 60%) groups. These results suggest that the visual scene presented in the VE may have contributed to a higher awareness of the olfactory stimuli dispensed during the immersion. This impression is in line with the findings of previous studies reporting that higher degrees of semantic concordance between an odour and a picture facilitate olfactory detection (Gottfried & Dolan, 2003). At the same time, the control group's non-negligible 15% rate of false positives is reminiscent of the wine tasting experiment (Morrot, Brochet, & Dubourdieu, 2001) that demonstrated how visual information can mislead the olfactory sense.

Whether measured *in virtuo* (for PLE, $n = 7$; for UNP, $n = 19$) or *in vivo* (for PLE, $n = 20$; for UNP, $n = 20$), the unpleasant odour was statistically significantly more unpleasant, and more concordant with the visual scene. While the unpleasant odour's *in virtuo* and *in vivo* familiarity scores surpassed those of the pleasant odour, the difference only reached statistical significance *in virtuo*. Finally, while the unpleasant odour's intensity score exceeded that of the pleasant odour both *in vivo* and *in virtuo*, none of these differences reached statistical significance. Thus, the *in virtuo* and *in vivo* results could be amalgamated as follows: compared to the pleasant odour, the unpleasant one was perceived as more unpleasant and concordant with the visual scene, with a tendency to be less familiar, but with no difference in intensity. The fact that there was no difference in intensity suggests that, in this particular case, the difference in conscious detection rate might, contrary to a hypothesis put forward by Baus and Bouchard (2016), not be related to perceived intensity.

No statistically significant difference was detected between the levels of Presence of the PLE and AMB groups. This result is similar to that reported by Baus and Bouchard (2016). However, it must be pointed out that in this experiment, there was a particularly low level of concordance between the pleasant smell of apple pie and the extremely dirty visual scene. According to the per-immersion brief repeated measures of Presence, there was a statistically significant Condition X Time interaction effect between the AMB and UNP groups; the size of the effect was small. This result is in line with the results found by Baus and Bouchard (2016). The slightly higher effect size detected in this latest experiment may be attributable to the notably higher *in virtuo* concordance of the unpleasant odour with the visual scene. While the ITC-SOPI Spatial Presence subscale score was higher for the UNP group than for the AMB group, this difference was not statistically significant. Given the results related to the brief measure of Presence, this finding is somewhat surprising. However, it may be noted that Baus and Bouchard (2016) had also found a relatively large inter-instrument variability between the results of the per-immersion brief repeated measures and the one-time measure of the ITC-SOPI Spatial Presence subscale. In that previous study, however, both types of measures still produced statistically significant differences (i.e., the variability concerned only the effect size). The results of this experiment regarding the effect on brief measures of Presence and the lack of effect on the ITC-SOPI Spatial Presence subscale are not diametrically opposed, but they do lead to a dilemma regarding the conclusions to be drawn. The multiple questions of the ITC-SOPI questionnaire give it an edge in terms of validity. However, the per-immersion brief repeated measures of Presence have the advantage of being taken during the immersion (thus eliminating the possibility of recall bias), controlling the between-subject variability, and capturing changes in score over time. Considering the notable number of individual factors that have been found to potentially affect Presence (for review, see Sacau, Laarni, & Hartman, 2008), a within-subject repeated measures design may give a more accurate picture than a one-time independent measure via questionnaire (as suggested by Jones, Bowers, Washburn, Cortes, and Satya, 2004).

As had been the case in Baus and Bouchard (2016), the experimental conditions were grouped according to the dimension of odours that could best be controlled, pleasantness. However, it seemed pertinent to examine the correlations between Presence and each of the four odour dimensions measured as part of the project. The calculations were based on the 26 participants (for PLE, $n = 7$; for UNP, $n = 19$) who consciously perceived the applicable olfactory stimulus in the VE (out of 40 participants exposed). Unfortunately, these results varied notably depending on the instrument used to measure Presence. In the case of the Presence Residuals (derived from the per-immersion brief repeated measures of Presence), Presence correlated in a strong, negative, statistically significant manner with Familiarity. While not statistically significant, there was also a weak negative relation with Pleasantness and a weak positive relation with Concordance. In the case of the ITC-SOPI, Presence correlated in a strong, positive, statistically significant manner with Concordance. While not statistically significant, the moderate positive relationship with Intensity is also worth mentioning. Taken as a whole, these results suggest that concordance with the visual scene had the highest impact on Presence; this conclusion is similar to that reported by Baus and Bouchard (2016).

Although a secondary measure, the results pertaining to the sense of Reality are quite interesting. In their previous experiment, using a VE devoid of objects linking the visual scene to any of the odours, Baus and Bouchard (2016) had found that exposure to neither odour had an effect on Reality. This time, using a very dirty virtual kitchen that “looks to smell bad,” exposure to the unpleasant odour led to a statistically significantly higher Reality score than the ambient air. The effect size was small. No such difference was detected between the PLE and AMB groups. These results suggest that the concordance between the dirty kitchen and the unpleasant odour may have contributed to a higher sense of Reality.

As measured via the Ecological Validity subscale of the ITC-SOPI, exposure to the pleasant odour had no statistically significant effect on the sense of Realism. Exposure to the unpleasant one, however, did increase the sense of Realism in a statistically significant manner; the effect size was large. This result differs from the findings of Baus and Bouchard (2016) and suggests that the match between the dirty kitchen and the unpleasant odour may have contributed to a higher sense of Realism.

Limitations

The limitations include the risk of creating a break in Presence when questioning the participant per-immersion, and the difficulty controlling interpersonal differences in a one-time assessment design. Limitations related to the persistence of odours include the restriction of always having to visit the odorous room after the inodorous room, making it impossible for the experimenter to control the order effect. A fuller description of these limitations can be found in Baus and Bouchard (2016).

Conclusions and recommendations

The results of this study suggest that, in a VE that includes visual elements normally associated with an unpleasant smell, the effect of exposure to an unpleasant odour notably affects the overall quality of the user experience in VR. More specifically, it can affect the senses of Presence, Reality, and Realism. Furthermore, when previous results from Baus and Bouchard (2016) are taken into account, the results of this latest study suggest that, in a VE, a higher level of visual/olfactory concordance can increase the conscious detection rate of an unpleasant odour.

While the results of this experiment give strong support to the possibility of increasing the quality of the user experience in VEs by matching visual and olfactory cues, it addresses this issue only in the context of an unpleasant odour. As reported by Baus and Bouchard (2016) and again in this experiment, the low conscious *in virtuo* detection rate of the pleasant odour poses a problem: is the pleasant odour’s lack of effect on Presence related to the low conscious detection rate, the low visual/olfactory concordance, or does a pleasant odour simply have no effect on Presence in VR? To answer this question, and given that a match between a visual scene and an olfactory cue seems to influence the conscious detection rate of an odour, it could be interesting to repeat this protocol in a VE that matches the pleasant odour with a concordant visual scene.

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Table 1

Sociodemographic Description of Participants in the Three Odorant Conditions (N = 60)

Measure	Ambient (AMB) *n* = 20	Pleasant (PLE) *n* = 20	Unpleasant (UNP) *n* = 20
Age	25.55 (6.50)	23.10 (5.54)	23.70 (5.35)
Dominant culture			
African	5%	0%	15%
North American	95%	100%	80%
South American	0%	0%	5%
Highest level of education completed			
Master's/Ph.D.	0%	10%	5%
Bachelor	10%	0%	20%
Pre-university college	75%	60%	55%
High school	15%	30%	20%

Note. Standard deviations of age are shown in brackets.

Table 2

Brief Measures of Presence and Reality collected in virtuo

Measure	Bedroom (control)		Kitchen (experimental)	
	M (*SD*)	95% CI	*M* (*SD*)	95% CI
Brief Presence				
Ambient	79.50 (10.99)	[74.36, 84.64]	80.00 (15.81)	[72.60, 87.40]
Pleasant	75.10 (15.02)	[68.07, 82.13]	77.75 (17.53)	[69.54, 85.96]
Unpleasant	75.90 (14.67)	[69.04, 82.76]	85.45 (12.07)	[79.80, 91.10]
Brief Reality				
Ambient	76.75 (12.80)	[70.76, 82.74]	76.00 (16.67)	[68.20, 83.80]
Pleasant	64.85 (23.90)	[53.67, 76.03]	66.40 (23.92)	[55.21, 77.59]
Unpleasant	75.40 (14.78)	[68.48, 82.32]	83.95 (13.47)	[77.64, 90.26]

Note. CI = confidence interval.

Table 3

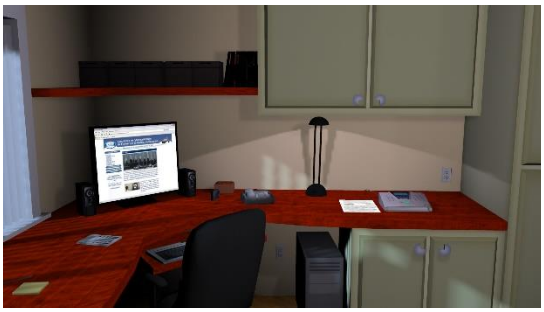
Relationship between Presence and Characteristics of Odours

Measure	Concordance	Pleasantness	Intensity	Familiarity
Change in Presence	.22	-.23	-.04	-.41*
ITC Spatial Presence	.47*	-.09	.37	.15

Note. Correlations are based on the PLE and UNP participants who detected an odour *in virtuo* (PLE = 7; UNP = 19).
* $p < .05$.

a. Bathroom layout

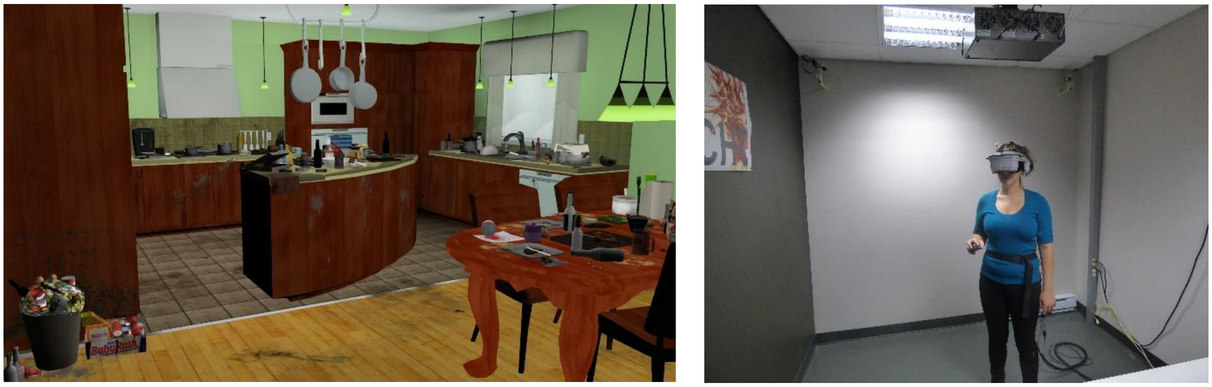
b. Living room layout



c. Office layout

d. Bedroom layout

Figure 1. Virtual rooms searched prior to the virtual kitchen.



a. Layout of dirty kitchen b. Participant in immersion

Figure 2. Virtual kitchen and immersion room.
Note. For the purpose of the photograph, the lights in the immersion room were left on. During the actual protocol, the immersion is carried out in the dark. The scent delivery system is the apparatus seen above the participant, in the centre of the immersion area.

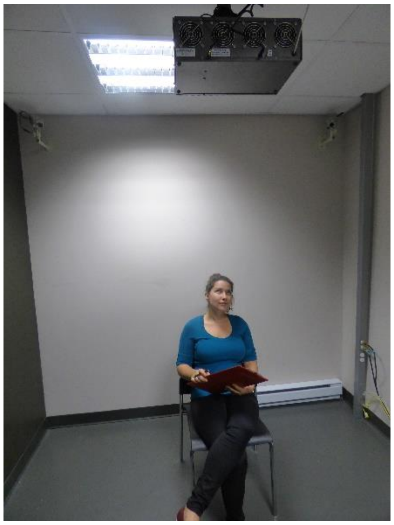


Figure 3. The 30-second *in vivo* exposure to the olfactory stimulus previously used in the virtual kitchen. The time needed for participants to detect the odour is measured, and they rate the characteristics of the odour.

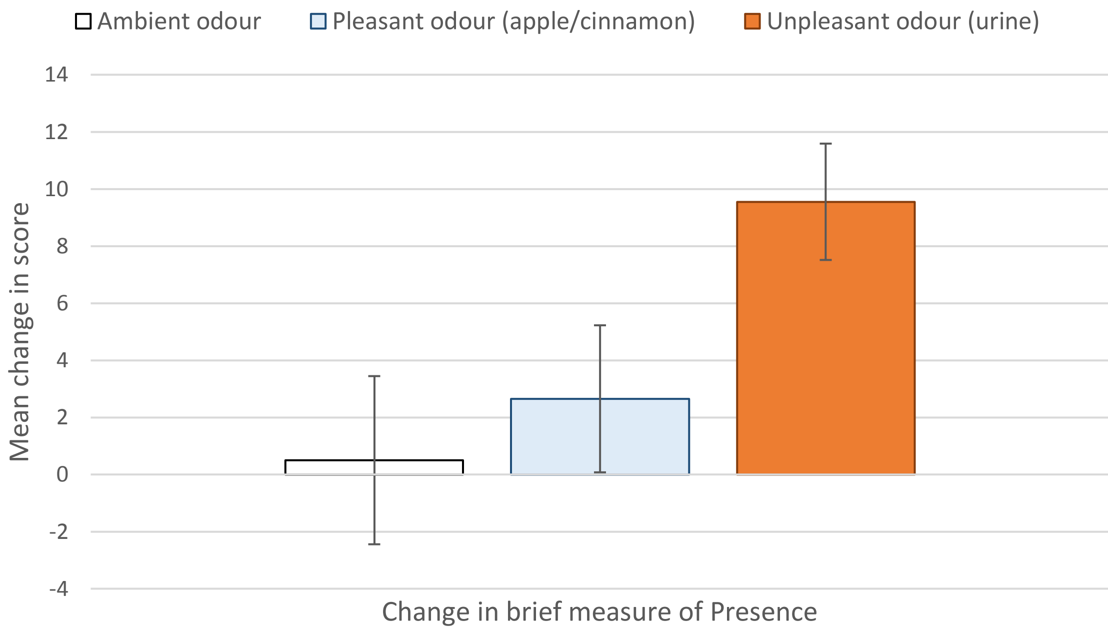


Figure 4. Illustration of the brief measure of Presence X Time interaction effect, as shown by mean change from the control to the experimental condition. Standard errors are represented in the figure by the error bars attached to each column.

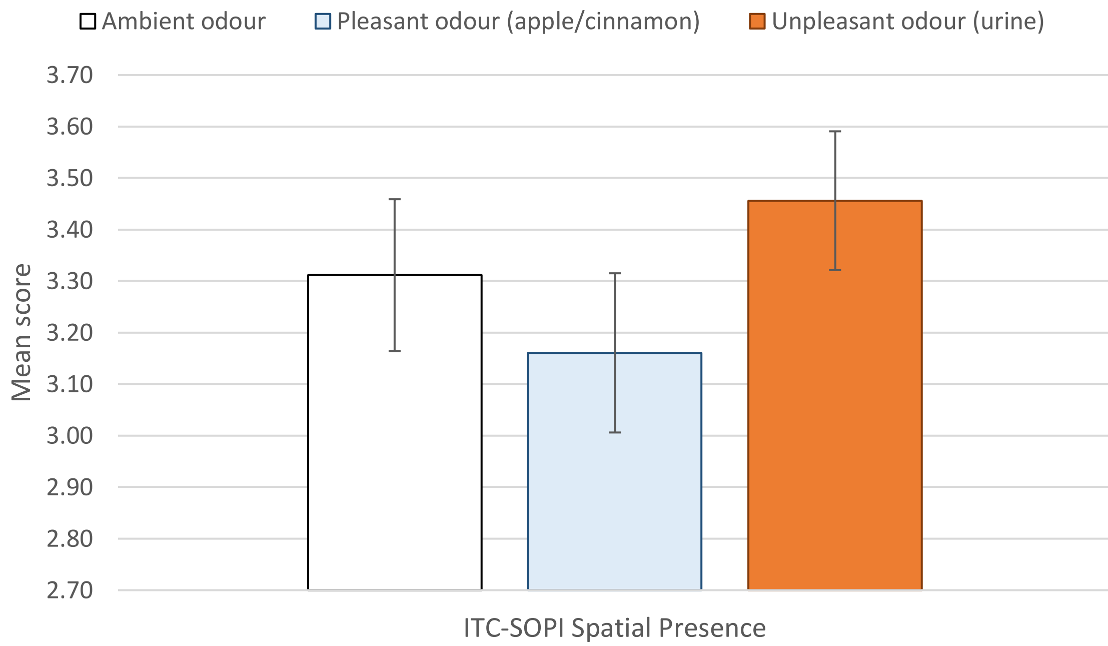


Figure 5. The sense of Presence (as measured by the Spatial Presence subscale of the ITC-SOPI). Standard errors are represented in the figure by the error bars attached to each column.

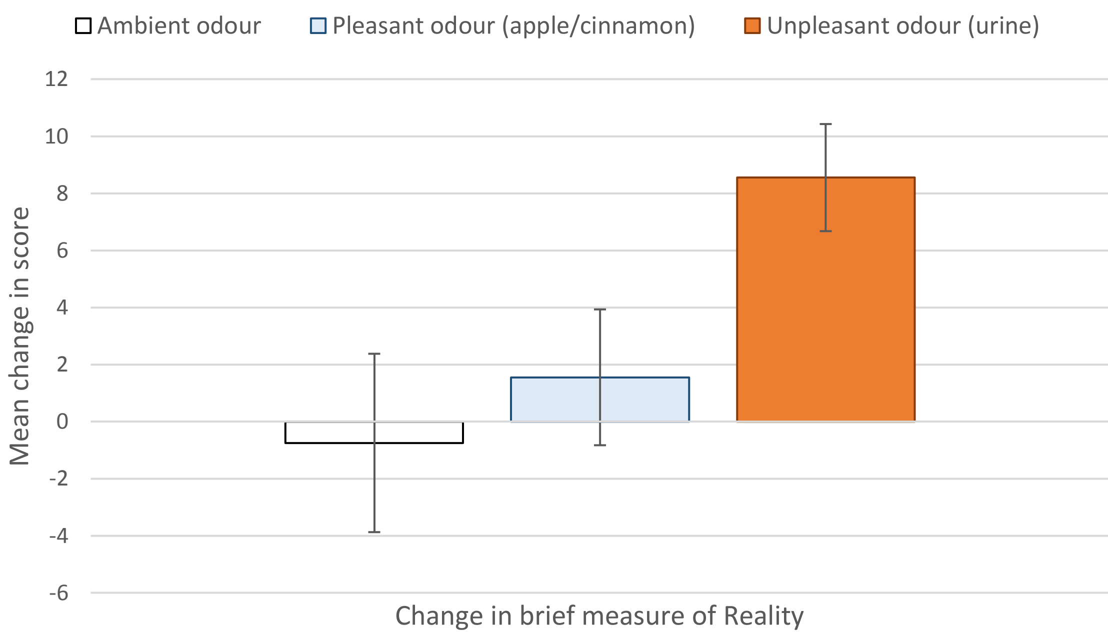


Figure 6. Illustration of the brief measure of Reality X Time interaction effect, as shown by mean change from the control to the experimental condition. Standard errors are represented in the figure by the error bars attached to each column.

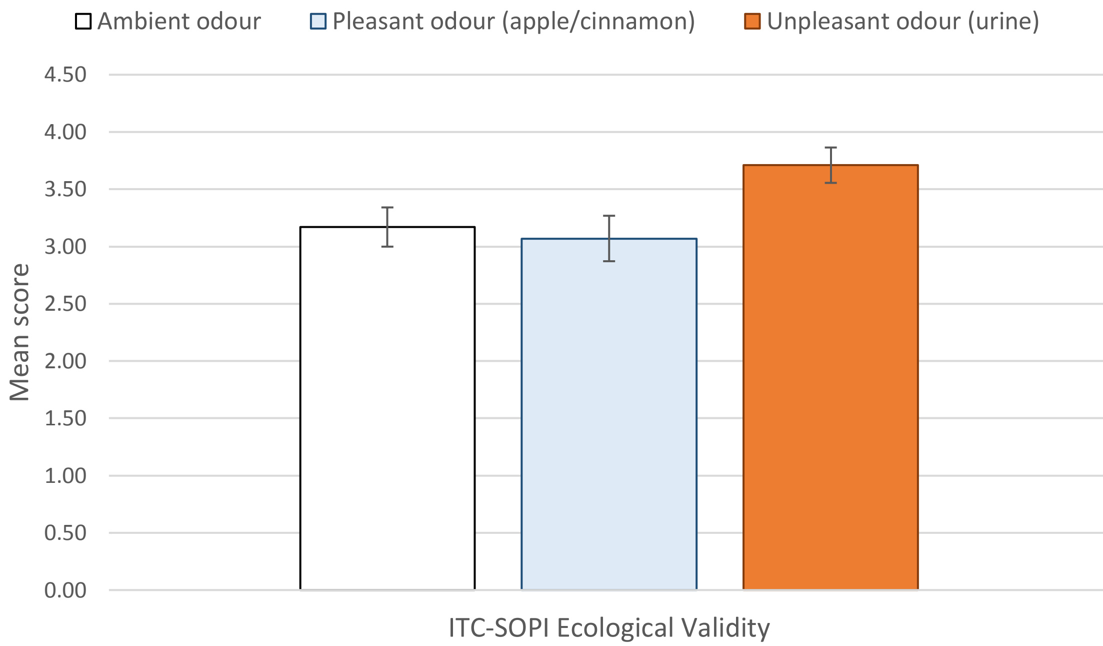


Figure 7. The sense of Realism (as measured by the Ecological Validity subscale of the ITC-SOPI). Standard errors are represented in the figure by the error bars attached to each column.

Appendix

Additional Analyses

Pre-Immersion Differences Between Groups

Multiple one-way ANOVAs verified whether the groups differed in terms of pre-immersion characteristics such as (a) age, (b) immersive tendencies, and/or (c) absorption tendencies.

Age. Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that the age of the AMB (M = 25.55; SD = 6.50; Mdn = 24.50), PLE (M = 23.10; SD = 5.54; Mdn = 22.00), and UNP (M = 23.70; SD = 5.35; Mdn = 22.00) groups did not differ in a statistically significant manner ($H(2) = 1.57$, $p = .46$).

Tendency to be immersed. The results of the one-way ANOVA did not reveal different immersion tendencies between the AMB, PLE, and UNP groups (respectively M = 56.75, SD = 14.20; M = 53.95, SD = 16.27; M = 54.80, SD = 14.34; $F(2, 57) = .18$, $p = .83$, $\eta_p^2 = .01$).

Tendency to be absorbed. The results of the one-way ANOVA did not reveal different absorption tendencies between the AMB, PLE, and UNP groups (respectively M = 1.77, SD = .61; M = 1.51, SD = .50; M = 1.66, SD = .61; $F(2, 57) = 1.05$, $p = .36$, $\eta_p^2 = .04$).

Immersion-Induced Negative Side Effects

ITC-SOPI. Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that the immersion-induced side effects experienced by the AMB (M = 2.25; SD = 1.01; Mdn = 2.00), PLE (M = 2.19; SD = .79; Mdn = 2.00), and UNP (M = 2.49; SD = .74; Mdn = 2.50) participants did not differ in a statistically significant manner ($H(2) = 1.96$, $p = .38$).

Simulator Sickness Questionnaire. Planned contrasts interaction for repeated-measures designs were used to verify the effect of the odours on cybersickness; there were three conditions (AMB, PLE, UNP) by two times (pre-immersion, post-immersion). Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that, pre-immersion, cybersickness levels among the AMB (M = .16; SD = .11; Mdn = .13), PLE (M = .21; SD = .16; Mdn = .22), and UNP (M = .24; SD = .14; Mdn = .25) groups did not differ in a statistically significant manner ($H(2) = 5.55$, $p = .06$). Post-immersion, cybersickness levels among the AMB (M = .42; SD = .29; Mdn = .34), PLE (M = .43; SD = .29; Mdn = .31), and UNP (M = .46; SD = .27; Mdn = .44) groups did not differ in a statistically significant manner, either ($H(2) = .34$, $p = .84$). Within groups, Wilcoxon tests detected differences between pre- and post-immersion cybersickness for the AMB ($z = -3.47$, $p = .00$, $r = -.55$), PLE ($z = -2.87$, $p = .00$, $r = -.45$), and UNP ($z = -3.12$, $p = .00$, $r = -.49$) groups. Overall, these results suggest that the levels of cybersickness did not differ in a statistically significant manner.

Characteristics of Olfactory Stimuli Detected In Virtuo

AMB group. For this group, 15% (3 out of 20) of the participants, 14.29% (1 out of 7) of the men and 15.38% (2 out of 13) of the women, reported having detected an odour in the kitchen while none had been released. All three participants attributed the source of the odour to a visual element of the kitchen (e.g., the dirty dishes). Only one of these participants (33.33%) stated that the odour was associated with a memory.

PLE and UNP groups. The detection rates, rate of association with a memory, and presumed source of odours are shown in Table A.

Table A

Detection, Association to Memory, and Source of Odours Detected In Virtuo

Measure	Pleasant odour (cinnamon apple pie)	Unpleasant odour (urine)
Detection rate		
All participants within condition	35%	95%
Males within condition	28.57%	85.71%
Females within condition	38.46%	100%
Rate of association with memory	57.14%	63.16%
Participants' presumed source of odour		
Element of VE	14.29%	84.21%
Imaginary source	71.43%	15.79%
Unknown	14.29%	0%

Comparison between the characteristics of the PLE and UNP odours. Due to the size disparity between the groups and in order to compare the characteristics of the PLE and UNP odours, non-parametric comparisons were conducted. These confirmed that, as assessed by the PLE (n = 7) and UNP (n = 19) participants who detected the odour *in virtuo*, the UNP odour was statistically significantly more unpleasant (Mdn = 3.00) than the PLE odour (Mdn = 1.00; U = 0.00, z = -3.99, p = .00, d = 9.67, r = .98), less familiar (Mdn = 3.00) than the PLE odour (Mdn = 5.00; U = 17.50, z = -2.88, p = .00, d = 6.93, r = .96), and more concordant with the visual scene (Mdn = 5.00) than the PLE odour (Mdn = 2.00; U = 26.50, z = -2.42, p = .02, d = -3.55, r = -.87). However, the differences between the PLE and UNP odours were not statistically significant in terms of Intensity (respectively $Mdns$ = 5.00 and 6.00; U = 58.50, z = -.48, p = .63, d = -1.10, r = -.48). Mean values and standard errors are shown in Fig. A.

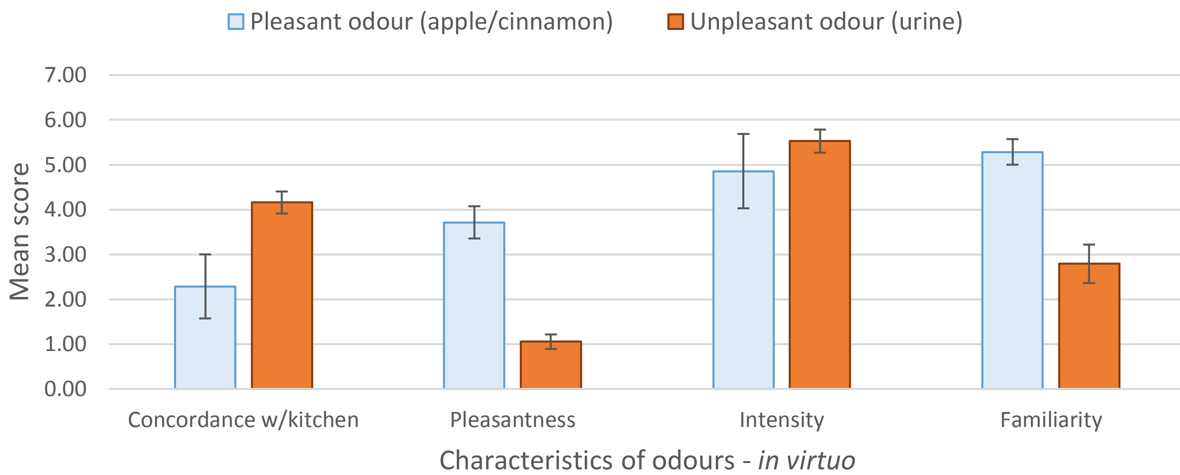


Figure A. Characteristics of olfactory stimuli presented *in virtuo*. These are based on the participants who reported having detected an odour in the kitchen (for pleasant odour, *n* = 7; for unpleasant odour, *n* =19). Standard errors are represented in the figure by the error bars attached to each column.

Characteristics of Olfactory Stimuli Detected In Vivo

PLE group. For the participants in this group, the post-experiment *in vivo* detection rate of the same olfactory stimulus that they had been exposed to in the kitchen was 100% (20 out of 20). Fifteen of the group's members (75%) stated that the odour was associated with a memory.

UNP group. For the participants in this group, the post-experiment *in vivo* detection rate of the same olfactory stimulus that they had been exposed to in the kitchen was 100% (20 out of 20). Eighteen of the group's members (90%) stated that the odour was associated with a memory.

Comparison between the characteristics of the PLE and UNP odours. Due to the non-normal distribution of the characteristics of the odours, and in order to compare the characteristics of the PLE and UNP odours, non-parametric comparisons were conducted. These confirmed that, as assessed by the participants in the PLE (*n* = 20) and UNP (*n* = 20) groups when they were exposed to the odour *in vivo* (post-questionnaires), the UNP odour was statistically significantly less pleasant (*Mdn* = 1.00) than the PLE odour (*Mdn* = 3.50; U = 0.00, z = -5.53, p = .00, d = 17.47, r = .99), and more concordant (*Mdn* = 3.50) with the visual scene than the PLE odour (*Mdn* = 2.00; U = 78.50, z = -3.36, p = .00, d = -5.58, r = -.94). However, the differences between the PLE and UNP odours were not statistically significant in terms of Intensity (respectively *Mdns* = 5.50 and 6.00; U = 143.50, z = -1.60, p = .11, d = -1.81, r = -.67) or Familiarity (respectively *Mdns* = 5.00 and 4.00; U = 135.50, z = -1.79, p = .07, d = 2.96, r = .83). Mean values and standard errors are shown in Fig. B.

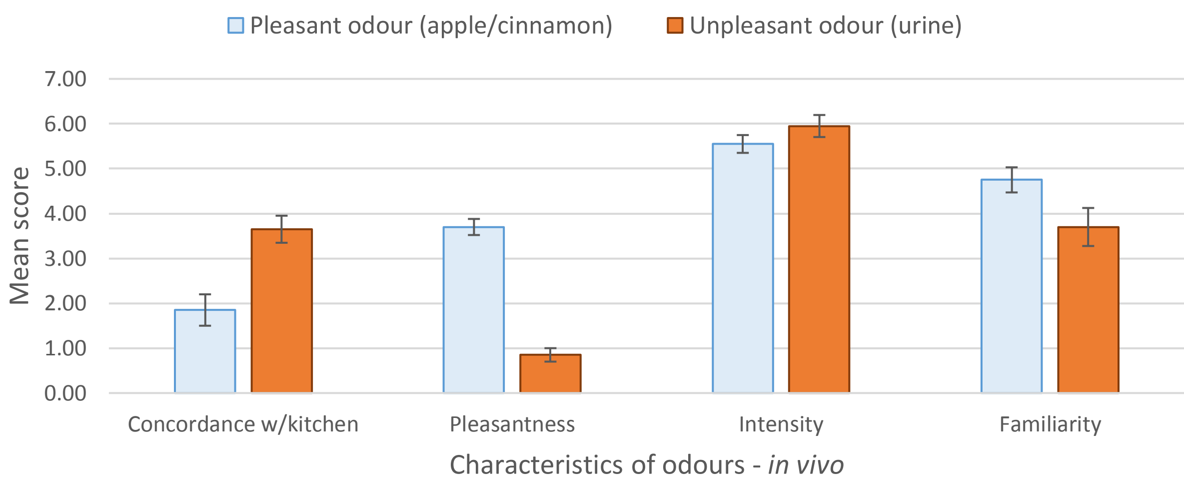


Figure B. Characteristics of olfactory stimuli presented *in vivo*. These are based on a 30-second exposure to the same stimulus that the participants were exposed to *in virtuo*. This time, however, the participants had been informed of the impending exposure to an olfactory stimulus (for pleasant odour, n = 20; for unpleasant odour, n = 20). Standard errors are represented in the figure by the error bars attached to each column.

Article 4

The Exposure to a Pleasant Odour Increases the Sense of Reality,

but not the Sense of Presence or Realism

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Abstract

Recently it was reported that in a filthy virtual kitchen, exposure to an unpleasant odour (thus concordant with the visual scene) increased the senses of Presence, Reality, and Realism. The objective of this project was to verify whether, in a virtual environment (VE) concordant with a pleasant odour, exposure to that odour would also increase the senses of Presence, Reality, and Realism. The experiment consisted in immersing three groups of randomly assigned participants (13 females and 7 males in each group) in a virtual kitchen where the visual scene suggested that cinnamon apple pies had recently been baked. While the control group was simply exposed to the ambient odour of the immersion room, the experimental groups were (unknowingly) exposed either to a pleasant odour of cinnamon apple pie or an unpleasant odour of urine. The results indicated that while exposure to the pleasant odour did increase the sense of Reality in a statistically significant manner, it did not affect the sense of Presence or Realism. Results also suggested that the visual/olfactory concordance may have facilitated the detection of the pleasant odour. The potential ramifications of the results, potential explanations for the lack of effect on the sense of Presence, as well as potential follow-up research projects are discussed.

Keywords: virtual reality, presence, olfaction, odours, reality, realism

The Exposure to a Pleasant Odour Increases the Sense of Reality, but not the Sense of Presence or Realism

Introduction

In 1962, with notably more modest technological means than those available today, Heilig's (1962) Sensorama - a system considered by some as the ancestor of virtual reality (VR; Ghinea & Ademoye, 2011) - exposed users to stimuli of vision, sound, motion, vibration, wind, and odours. Since then, olfactory cues have been incorporated in VR applications used in the fields of entertainment (e.g., ChangHoon et al., 2002; Papin et al., 2003), training (e.g., Cater, 1994), and clinical psychology (e.g., Bordnick et al., 2008; Cukor, Spitalnick, Difede, Rizzo, and Rothbaum, 2009). However, despite the knowledge that olfactory receptors are a rich source of information to humans (Barfield & Danas, 1996), the integration of olfactory cues in VR is more of an exception than a rule. It has been suggested that this rarity may be linked to the difficulty producing and controlling odorants in a precise manner (Biocca & Delaney, 1995). Another potential contributing factor may be the scarcity of information regarding the actual effect of olfactory cues on the quality of the user experience in VR. Indeed, why use them if their effect is unknown? Most recently, in order to contribute to the body of research addressing this issue, Baus and Bouchard (2016a, 2016b) completed two separate studies investigating the link between odours and the quality of the user experience. More precisely, they examined how exposure to pleasant and unpleasant odours could affect the senses of Presence, Reality, and Realism in VR.

To this end, Baus and Bouchard (2016a) immersed two groups of experimental participants and one group of control participants ($N = 60$) in a VE devoid of objects linking the visual scene with either a pleasant or unpleasant odour (prior to the immersion, the participants had been given no indication that they could be exposed to odorants). The results, measured via repeated measures taken during the immersion and a post-immersion questionnaire, suggested that the exposure to the unpleasant odour, but not to the pleasant one, increased the sense of Presence, while neither odour had an effect on the sense of Reality or Realism. The authors hypothesized that the particularly low 15% conscious detection rate of the pleasant odour may have contributed to its lack of effect on Presence.

Baus and Bouchard (2016b) repeated the experiment with two slight modifications. While they used the same material and procedures as in their previous project, this time they also measured (post-immersion) the time required by the participants in the experimental groups to detect, *in vivo*, the olfactory stimulus that they had been exposed to *in virtuo*. Another change concerned the VE itself. Instead of measuring the dependent variables in a virtual room devoid of objects linking the visual scene to the experimental odours, this time the authors used a virtual room designed to look like it smells unpleasant (i.e., it was extremely dirty). Their first finding concerned the odour detection rate: they found a 95% conscious detection rate of the unpleasant odour. This represents a notable increase from the 60% conscious detection rate of that same odour in a room devoid of objects establishing an obvious link between the visual scene and the odours (Baus & Bouchard, 2016a). The authors concluded that the high level of visual/olfactory concordance may have contributed to this increase. Another interesting finding concerned the 15% false positive detection rate of the control group. In this case, the authors suggested that the filthiness of the virtual room may have contributed to olfactory illusions.

With respect to the quality of the user experience measures, the results suggested that, in the dirty virtual room, exposure to the unpleasant odour had a statistically significant effect on the senses of Presence (as measured during immersion via repeated brief measures), Reality, and

Realism. While the effect size was small for both Presence and Reality, it was large for Realism. When put in context with Baus & Bouchard's (2016a) findings, these latest results suggest that the high level of visual/olfactory concordance notably increased the overall quality of the user experience in VR. The results regarding exposure to the pleasant odour were quite different. There was no statistically significant effect on any of the quality of the user experience measures. However, the 35% conscious detection rate of the pleasant odour left some room to speculate about whether this lack of effect was linked to the lack of conscious detection or whether the pleasant odour simply has no effect on the quality of the user experience.

In sum, the results of these two experiments (Baus & Bouchard, 2016a, 2016b) suggest that exposure to an unpleasant odour can have a statistically significant effect on Presence, and that, if the visual scene is concordant with the unpleasant odour, this effect can extend to the senses of Reality and Realism. While the results relating to the effect of exposure to a pleasant odour on the quality of the user experience decisively point to a negative response, the low *in virtuo* conscious detection rate of the pleasant odour and the discordance between the visual and olfactory stimuli do leave some room for further investigation.

Thus, it was the ambition of this project to verify the effect of exposure to a pleasant odour on the quality of the user experience in a VE visually concordant with that pleasant odour. As in the two previous projects by Baus and Bouchard (2016a, 2016b), the quality of experience was to be measured via the senses of Presence (primary dependent variable), Reality, and Realism (exploratory dependent variables). At the same time, it was also of interest to see how the visual/olfactory concordance would affect the conscious detection rate of the pleasant odour.

The research hypothesis for this experiment stated that in a virtual kitchen where visual stimuli suggest that cinnamon apple pies had recently been baked, exposure to a pleasant cinnamon apple pie odour will be associated with a statistically significantly higher level of Presence than exposure to the ambient odour.

Method

General

The experimental procedure was identical to that followed by Baus and Bouchard (2016a), with the following modifications: (a) while Baus and Bouchard's (2016a) virtual kitchen was devoid of objects that could be associated with the experimental odours, the virtual kitchen used in this latest experiment included items associated with the pleasant odour; and (b) a post-immersion procedure aiming to measure the time to detect each of the experimental odours was added.

Participants

The 60 participants (21 males and 39 females) were recruited via adverts and class visits on local university and college campuses. The inclusion and exclusion criteria used by Baus and Bouchard (2016a) were also applied for this project. The group mean ages, dominant cultural influence (by continent), and highest level of education completed are shown in Table 1.

Insert Table 1

Material

The VR system consisted of an NVIS nVisor SX60 head-mounted display, an InterSense InertiaCube3, a six-degrees-of-freedom tracking system, and a Virtools (version 5)-generated VE. The scent delivery system consisted of an SDS100 Scent Palette (Biopac Systems, Inc.) and two scent cartridges (Biopac Systems, Inc.). For a detailed description, see Baus and Bouchard (2016a). The VE (see Fig. 1) was identical to that used by Baus and Bouchard (2016a) except that, in this case, there were two apple pies on the counter of the virtual kitchen as well as utensils and ingredients required to make a cinnamon apple pie (e.g., apples, cinnamon sticks, flour; see Fig. 2).

Insert Figure 1

Insert Figure 2

Overview of the the Protocol

The protocol was identical to that followed by Baus and Bouchard (2016a), except that when the participants in the experimental groups were re-exposed to the experimental odour *in vivo* post-immersion (see Fig. 3), the time required to detect the odour was measured (see *Instruments* section, *Measures of olfactory perception* subsection).

Insert Fig. 3

Instruments

General information measures. The participants' stereoscopic vision was assessed using the Randot[R] Stereotest (Stereo Optical Company, Inc.; www.stereooptical.com), and a Topcon PD-5 pupilometer (Topcon Medical Systems, www.topconmedical.com) was used to measure the interpupillary distance. The participants' olfactory function was verified via the Quick Smell Identification[TM] Test (Q-SIT; Sensonics, Inc., Haddon Heights, NJ), and a questionnaire was used to collect sociodemographic variables. A fuller description of the instruments can be found in Baus and Bouchard (2016a).

Quality of experience measures (dependent variables). The senses of Presence, Reality, and Realism were used to measure the quality of the experience in the VE. Presence is defined as the impression of being in the VE (Heeter, 1992); Reality is defined as the degree to which the user experienced the immersion as real (Baños, Botella, Garcia-Palacios, Villa, Perpiña, & Alcañiz, 2000); and Realism is defined as the degree to which the synthetic stimuli were similar to their non-synthetic counterparts (Baños, Botella, Garcia-Palacios, Villa, Perpiña & Alcañiz, 2000). The senses of Presence and Reality were measured during the immersion via brief verbal measures. Post-immersion, the senses of Presence and Realism were measured using, respectively, the Spatial Presence subscale of the Independent Television Commission Sense of Presence Inventory (ITC-SOPI; Lessiter, Freeman, Keogh, & Davidoff, 2001) and the Ecological Validity / Naturalness subscale of the ITC-SOPI (Lessiter, Freeman, Keogh, & Davidoff, 2001). A fuller description of these instruments can be found in Baus and Bouchard (2016a).

Measures of potential moderators of the human experience in synthetic environments. Pre-immersion, the Immersive Tendencies Questionnaire (ITQ; Witmer &

Singer, 1998), the Modified Tellegen Absorption Scale (MODTAS; Jamieson, 2005), the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993), and the Negative Effects subscale of the ITC-SOPI (Lessiter, Freeman, Keogh, & Davidoff, 2001) were administered to control for potential covariates of Presence. A fuller description of these instruments can be found in Baus and Bouchard (2016a).

Measures of olfactory perception. Once the post-immersion quality of experience questionnaires were completed, a questionnaire on *in virtuo* odour perception was administered to all participants. Participants in the PLE and UNP groups were then re-exposed, this time *in vivo*, to their respective olfactory stimulus for 30 seconds, during which time they completed a questionnaire on the odour's characteristics. A fuller description of these instruments can be found in Baus and Bouchard (2016a). In addition, during the *in vivo* exposure to the olfactory stimulus, the time required by each participant to detect the odour was measured.

Results

IBM SPSS Statistics 22 was used for all statistical analyses. Assumptions were verified prior to each analysis; non-parametric tests were carried out, if applicable.

Analysis of Control Variables and Manipulation Checks

Pre-immersion differences between groups. A Kruskal-Wallis test and one-way ANOVAs indicated that the groups did not differ in age, immersive tendencies, or absorption tendencies (see Appendix for detailed results).

Immersion-induced negative side effects. A one-way ANOVA and a combination of Kruskal-Wallis and Wilcoxon tests revealed no differences between groups in terms of immersion-induced negative side effects (see Appendix for detailed results).

Characteristics of olfactory stimuli detected in virtuo. The detection rates of the PLE and UNP odours were, respectively, 75% and 80%. The characteristics of the PLE and UNP odours and a comparative analysis of these are presented in the Appendix.

Characteristics of olfactory stimuli detected in vivo. Due to the non-normal distribution within the groups, and in order to compare the time to detect the PLE and UNP odours, a non-parametric comparison was conducted. It confirmed that there was no statistically significant difference between the number of seconds required to detect the pleasant ($M = 5.35$, $S.D. = 2.11$) and unpleasant ($M = 5.25$, $S.D. = 1.75$; $U = 199.00$, $z = -.03$, $p = .98$) odours. The detection rates and characteristics of the PLE and UNP odours, as well as a comparison of these characteristics, can be found in the Appendix.

Analysis of Dependent Variables

The sense of Presence.

Brief measure of Presence. Due to the inequality of variances (bedroom) and non-normal distribution of Presence in the UNP group (kitchen), non-parametric tests were conducted. The results of Mann-Whitney tests indicated that the Presence levels did not statistically significantly differ between the AMB and PLE groups and between the AMB and UNP groups, neither in the bedroom (respectively, $U = 187.50$, $z = -.34$, $p = .73$, $d = -0.33$, $r = -0.16$; and $U = 189.50$, $z = -.29$, $p = .77$, $d = -0.19$, $r = -0.09$) nor the kitchen (respectively, $U = 197.50$, $z = -.07$, $p = .95$, $d = -0.16$, $r = -0.08$; and $U = 196.00$, $z = -.11$, $p = .91$, $d = -0.12$, $r = -0.06$).

Within groups, Wilcoxon tests detected a statistically significant time effect for the AMB ($z = -2.23$, $p = .03$, $r = -.35$), PLE ($z = -3.43$, $p = .00$, $r = -.54$) and UNP ($z = -2.57$, $p = .01$, $r = -.41$) groups. Overall, these results suggest that neither the pleasant nor the unpleasant odour had a statistically significant effect on the brief measure of Presence. Mean values and standard deviations are shown in Table 2, and an illustration of the interaction is shown in Fig. 4.

Insert Table 2

Insert Figure 4

Spatial Presence subscale of the ITC-SOPI. In order to verify the effect of the odours on Spatial Presence, planned comparisons were used. These revealed that neither the level of Spatial Presence for the PLE group nor that for the UNP group differed in a statistically significant manner from the level of Spatial Presence for the AMB group (respectively, $t = .54$, $p = .59$, $d = -.18$, r = -.09; and $t = .80$, $p = .43$, $d = -.25$, r = -.12). Mean values and standard errors are shown in Fig. 5.

Insert Figure 5

Relationship between Presence and the characteristics of the odours. In order to verify the potential relationship between Presence and the characteristics of the perceived odour, correlations were calculated. To this end, using the brief measures of Presence in the bedroom and in the kitchen, Presence residual gain scores were calculated (see Manning & Dubois, 1962; Tracy & Rankin, 1967). A verification of the assumptions revealed no potential outliers in the level of either Congruency, Pleasantness, Intensity, Familiarity, or Concordance with the visual scene. According to the results of the Shapiro-Wilk test (respectively for Congruency, Pleasantness, Intensity, and Familiarity: $p = .00$, $p = .00$, $p = .01$, $p = .01$), neither of the characteristics was distributed normally. The results of the Spearman correlations revealed that Intensity is related to Spatial Presence. Detailed results are shown in Table 3.

Insert Table 3

The sense of Reality.

Brief measure of Reality. Due to the non-normal distribution of Reality in the UNP (bedroom) and PLE (kitchen) groups, non-parametric tests were conducted. The results of Mann-Whitney tests indicated that the Reality levels for the AMB and PLE groups and those for the AMB and UNP groups did not statistically significantly differ either in the bedroom (respectively, U = 155.50, z = -1.21, p = .23, d = -.34, r = -.17; and U = 194.00, z = -.17, p = .87, d = -.11, r = -.05) or in the kitchen (respectively, U = 181.50, z = -.50, p = .62, d = .01, r = .01; and U = 159.00, z = -1.12, p = .26, d = .33, r = .16). Within groups, Wilcoxon tests detected a statistically significant time effect for the PLE condition (z = -2.22, p = .02, r = -.05), but not for the AMB (z = -.32, p = .75, r = -.37) and UNP (z = -1.72, p = .09, r = -.27) groups. Mean values and standard deviations are shown in Table 2, and an illustration of the interaction is shown in Fig. 6. Overall, these results suggest that the pleasant odour did affect the level of Reality in a statistically significant manner.

Insert Figure 6

The sense of Realism.

Ecological Validity subscale of the ITC-SOPI. In order to verify the effect of the odours on Ecological Validity, planned comparisons were used. These revealed that neither the level of Realism for the PLE group nor that for the UNP group differed in a statistically significant manner from the level of Realism for the AMB group (respectively, $t = .43$, $p = .67$, $d = -.14$, $r = -.07$; and $t = .97$, $p = .33$, $d = -.29$, $r = -.14$). Mean values and standard errors are shown in Fig. 7.

Insert Figure 7

Discussion

The research hypothesis for this experiment stated that in a virtual kitchen where visual stimuli suggest that cinnamon apple pies had recently been baked, exposure to a pleasant cinnamon apple pie odour will be associated with a statistically significantly higher level of Presence than exposure to the ambient odour. While a manipulation check confirmed that the apple/cinnamon odour was indeed pleasant and concordant with the visual scene, the research hypothesis was not confirmed. However, the results did provide interesting insight into the detection of odours in VR and the effect of a pleasant and concordant odour on the sense of Reality.

The relatively high and equal conscious detection rates of the pleasant and unpleasant odours (75% for PLE and 80% for UNP) are interesting. In previous experiments using visual scenes not specifically concordant with the pleasant odour (see Baus & Bouchard, 2016a, 2016b), the conscious detection rates of that same odour were notably lower than those found in the present experiment. The latest results support Baus & Bouchard's (2016b) conclusion that visual/olfactory concordance in a VE can facilitate the conscious detection of an odour. At the same time, it is worth noting that, despite the unpleasant odour's notably lower level of concordance with the visual scene, its conscious detection rate slightly exceeded that of the pleasant and concordant odour. These latest observations, combined with Baus and Bouchard's (2016a, 2016b) previous results, suggest that the conscious detection of a pleasant odour in VR may rely more on a favourable visual/olfactory concordance compared to an unpleasant one.

No statistically significant difference was detected between the AMB group's brief measures of Presence and that of either the PLE or UNP group. A closer look at the PLE and UNP groups' results showed statistically significantly higher levels of Presence in the kitchen than in the bedroom. However, the increases were insufficient to reach statistically significant differences with the AMB group. Given the results previously reported by Baus and Bouchard (2016a, 2016b), these latest findings were surprising. However, an examination of the AMB group's scores led to an interesting observation: there was a statistically significant difference between the AMB (control) group's Presence scores in the bedroom and the kitchen. As this had not been the case in either of the two previous experiments (see Baus & Bouchard, 2016a, 2016b), it was somewhat unexpected and called for further investigation. In an effort to identify differences between the three AMB groups, the following potential variables were uncovered: the present experiment took place in spring/summer, while the previous two took place in fall/winter; the participants; and the visual scene in the kitchen. Of those possibilities, the latter seems of particular interest. Could the sight of the cinnamon apple pie and ingredients have led to the control group's increased sense of Presence in the kitchen? If so, could the kitchen's visual scene also have increased the sense of Presence of the experimental groups? In turn, could the expression of the additional effect related to the olfactory exposure have been impeded by a ceiling effect? At this point, this sequence of events is merely speculative. However, in a future project, it may be worthwhile verifying whether the addition of location-concordant objects (e.g., cinnamon apple pies and ingredients in a kitchen, or a computer and office supplies in an office) can affect the sense of Presence in VR.

While in this latest experiment the increases in Presence (as measured by repeated brief measures) among the AMB and PLE groups did not differ significantly, the PLE group's level of Presence did increase by 8.1% when the detection rate was 75%. This result is similar to the 9.6% increase in Presence observed in a condition of olfactory/visual concordance with the unpleasant odour and a detection rate of 95% (see Baus & Bouchard, 2016b). Furthermore, Baus and Bouchard (2016a) had reported that with a condition of relatively neutral concordance and a detection rate of 60%, exposure to an unpleasant odour led to a Presence increase of 4.9%. Taking a look at trends over these three experiments, it seems that greater concordance favoured higher detection rates, and that higher detection rates favoured greater increases in Presence.

Regarding the ITC-SOPI Spatial Presence scores, the AMB group yielded an average score that was lower than those of the PLE and UNP groups; however, none of the differences were statistically significant. These results are similar to those reported by Baus & Bouchard (2016b).

It was of interest to verify whether any one odour characteristic played a greater role in the level of Presence. To this end, correlations were calculated between each of the characteristics of the odours perceived *in virtuo* and (a) the Presence Residuals (derived from the brief repeated measures of Presence taken during immersion); and (b) the ITC-SOPI Spatial Presence score. The results suggest that an odour's Intensity, followed by its Familiarity and then Concordance, correlated highest with the sense of Presence. These results differ from previous findings indicating that the level of visual/olfactory concordance correlated highest with the sense of Presence (see Baus & Bouchard, 2016a, 2016b). It is unclear as to why this particular experiment yielded different results. However, it may be of importance to note that, unlike in Baus and Bouchard (2016a, 2016b) where the measures related to the unpleasant/concordant odour notably outnumbered those related to the pleasant one, these latest correlations are the product of a more balanced representation of the odours (for PLE, $n = 15$; for UNP, $n = 16$). These latest results indicating that Intensity correlates highest with Presence somewhat supports the hypothesis that an odour needs to be consciously detected to have an effect on the sense of Presence, and that concordance may only play a supporting role with the detection rate.

The results also suggest that, in a VE visually concordant with a pleasant odour, exposure to the pleasant odour had a statistically significant effect on the sense of Reality. This outcome is in line with the findings that in a VE visually concordant with an unpleasant odour, exposure to an unpleasant odour has a statistically significant effect on the sense of Reality (Baus & Bouchard, 2016b). As this point, one may be tempted to assert that the level of pleasantness has no influence on the sense of Reality, and that it is solely the odour's concordance with the visual scene that affects the sense of Reality. The statistically significant result certainly does support that statement. However, looking beyond statistical significance, it must also be noted that in this latest experiment, the exposure to the discordant unpleasant odour was close to reaching statistical significance. This observation is particularly interesting because, unlike in other studies (see Baus & Bouchard, 2016a, 2016b), the number of conscious odour detections was relatively even between the PLE and UNP groups, as were the increases in Reality scores. These results may indicate that it is not the pleasant/unpleasantness of the odour or its concordance/discordance with the visual scene that affects the sense of Reality in VR, but the conscious detection of an odour, any odour.

Neither exposure to the pleasant and concordant or to the unpleasant and discordant odour had a statistically significant effect on the sense of Realism. This result is unlike the one reported by Baus and Bouchard (2016b), where they had found that exposure to an unpleasant odour in a visually concordant filthy kitchen led to a statistically significant higher sense of Presence.

Limitations

The limitations relating to the measurement of Presence included the risk of breaking the sense of Presence when questioning the participants during immersion. Furthermore, due to the persistence of odours once released in the environment, it was not possible to reverse the order in which the rooms were visited (i.e., the scented room was always visited last). A fuller description of these limitations can be found in Baus & Bouchard (2016a).

Conclusions and recommendations

This study revealed that in a virtual kitchen where the visual scene suggests that cinnamon apple pies had recently been baked, exposure to a pleasant odour of cinnamon apple pie significantly increased the sense of Reality, but not the sense of Presence or Realism. In addition, the results pertaining to the effect of the exposure to the unpleasant/discordant odour suggest that, in VR, the effect on Reality may be mainly dependent on the conscious detection of the odour and less on visual/olfactory concordance. If this hypothesis was to be verified in a future project, it could confirm that any consciously detected odour, be it pleasant/unpleasant or concordant/discordant, can affect the sense of Reality in VR.

The results of this experiment also lead to questions regarding the absence of a statistically significant difference in Presence between the control group and the group exposed to the pleasant/concordant odour. Why, unlike the control groups in the two previous experiments (see Baus and Bouchard, 2016a, 2016b), did this particular control group experience a statistically significantly higher level of Presence in the kitchen than in the bedroom? Was it, as hypothesized by the present authors, due to the presence of the cinnamon apple pies and ingredients on the kitchen counter? If so, did it also affect the experimental groups, and did it really lead to a ceiling effect that masked the effect of the odours on the sense of Presence? Investigating this issue via a replication of the present protocol, but using a three (ambient odour, pleasant odour, unpleasant odour) by two (neutral kitchen, cinnamon apple pie kitchen) design, may provide answers to these questions.

When examined in combination with the results of previous experiments using the same protocol and olfactory stimuli (see Baus & Bouchard, 2016a, 2016b), the results of the current study tend to confirm that visual/olfactory concordance favours the detection of a particular odour in VR. However, interestingly, over these three experiments, the *in virtuo* detection rate of the pleasant odour never surpassed that of the unpleasant odour, even when concordant with the visual scene.

The combined results of this study and Baus and Bouchard's previous studies (2016a, 2016b) also suggest that, while exposure to an olfactory stimulus can affect the senses of Presence and Reality in VR, conscious detection rate may play an important role in the relationship. This detection can be favoured via the concordance of visual and olfactory cues. It may be of interest to verify this hypothesis using a protocol specifically designed to verify the effect of an odour's perception on the senses of Presence, Reality, and Realism.

While additional studies are needed to confirm the new hypotheses, the combined results of this and previous studies (Baus & Bouchard, 2016a, 2016b) could already be of interest to developers of VR applications. In particular, the results could be operationalized in applications aiming to increase the levels of Presence and Reality (e.g., video games), as well as in those whose effects may be enhanced by the detection of a particular odour (e.g., the smell of Cordite in the treatment of combat-related PTSD).

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Table 1

Sociodemographic Description of Participants in the Three Odorant Conditions (N = 60)

Measure	Ambient (AMB) *n* = 20	Pleasant (PLE) *n* = 20	Unpleasant (UNP) *n* = 20
Age	27.25 (9.03)	26.45 (6.98)	24.80 (7.83)
Dominant culture			
African	10%	5%	5%
Asian	0%	5%	0%
European	15%	0%	0%
North American	75%	85%	95%
South American	0%	5%	0%
Highest level of education completed			
Master's/Ph.D.	10%	10%	10%
Bachelor	40%	20%	10%
Pre-university college	45%	45%	45%
High school	5%	25%	35%

Note. Standard deviations of age are shown in brackets.

Table 2

Brief Measures of Presence and Reality Collected In Virtuo

Measure	Bedroom (control)		Kitchen (experimental)	
	M (*SD*)	95% CI	*M* (*SD*)	95% CI
Brief Presence				
Ambient	76.75 (12.49)	[70.90, 82.60]	81.50 (11.48)	[76.13, 86.87]
Pleasant	71.20 (20.42)	[61.65, 80.65]	79.25 (16.80)	[71.39, 87.11]
Unpleasant	74.00 (17.14)	[65.98, 82.02]	80.00 (12.88)	[73.97, 86.03]
Brief Reality				
Ambient	72.90 (18.49)	[64.25, 81.55]	73.50 (15.99)	[66.02, 80.98]
Pleasant	66.60 (18.82)	[57.79, 75.41]	73.65 (18.21)	[65.13, 82.17]
Unpleasant	70.75 (20.73)	[61.05, 80.45]	78.00 (11.29)	[72.72, 83.28]

Note. CI = confidence interval.

Table 3

Correlations between Measures of Presence and Characteristics of Odours

Measure	Concordance	Pleasantness	Intensity	Familiarity
Change in Presence	.23	.11	.30	.23
ITC Spatial Presence	.03	-.14	.45*	.13

Note. Correlations are based on the PLE and UNP participants who detected an odour *in virtuo* (PLE = 15; UNP = 16).
* $p < .05$.

a. Bathroom layout

b. Living room layout

c. Office layout

d. Bedroom layout

Figure 1. Virtual rooms searched prior to the virtual kitchen.

a. Cinnamon apple pie kitchen layout　　b. Participant in immersion

Figure 2. Virtual kitchen and immersion room.
Note. The immersion room is shown here with the lights on; during the actual experimentation, the lights are turned off. The scent delivery system is fixed to the ceiling, in the middle of the immersion space.

Figure 3. Re-exposure to the olfactory stimulus, this time *in vivo*. Participants are re-exposed to the experimental olfactory stimulus for 30 seconds. Their time to detect the odour is measured and they evaluate the characteristics of the odour.

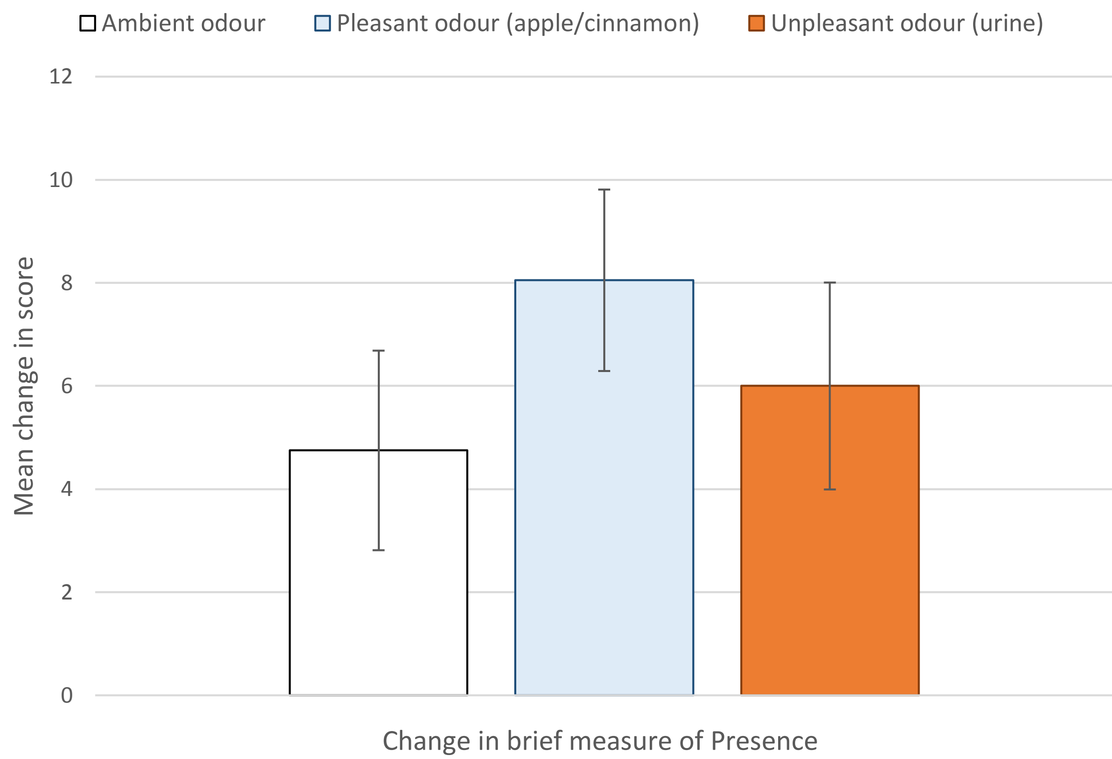

Figure 4. Illustration of the brief measure of Presence X Time interaction effect, as shown by mean change from the control to the experimental condition. Standard errors are represented in the figure by the error bars attached to each column.

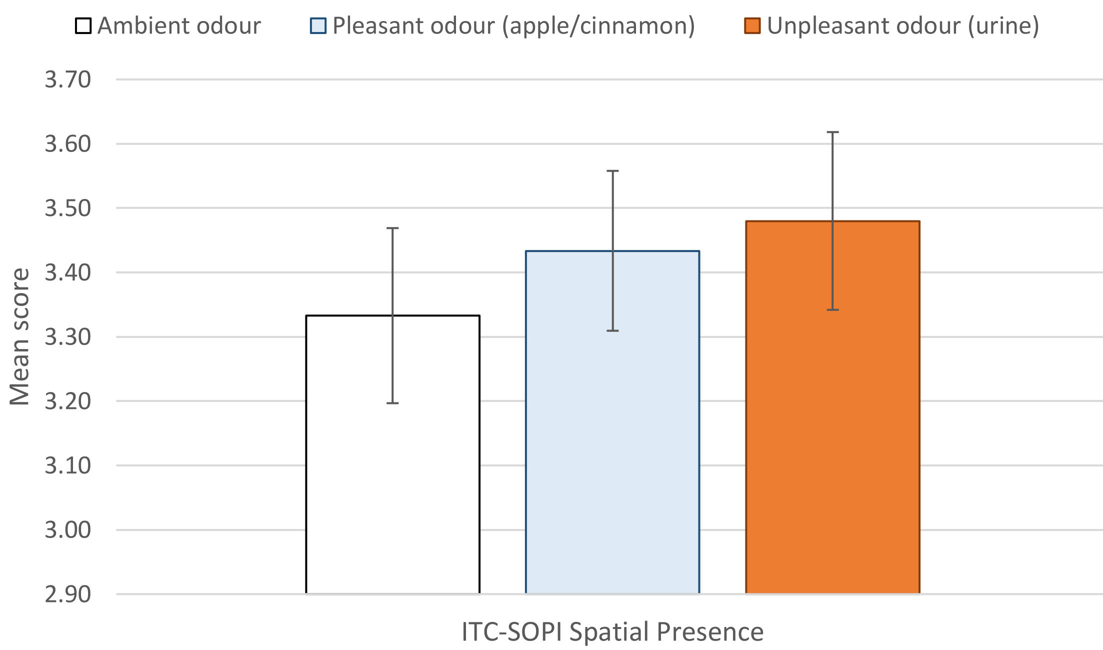

Figure 5. The sense of Presence (as measured by the Spatial Presence subscale of the ITC-SOPI). Standard errors are represented in the figure by the error bars attached to each column.

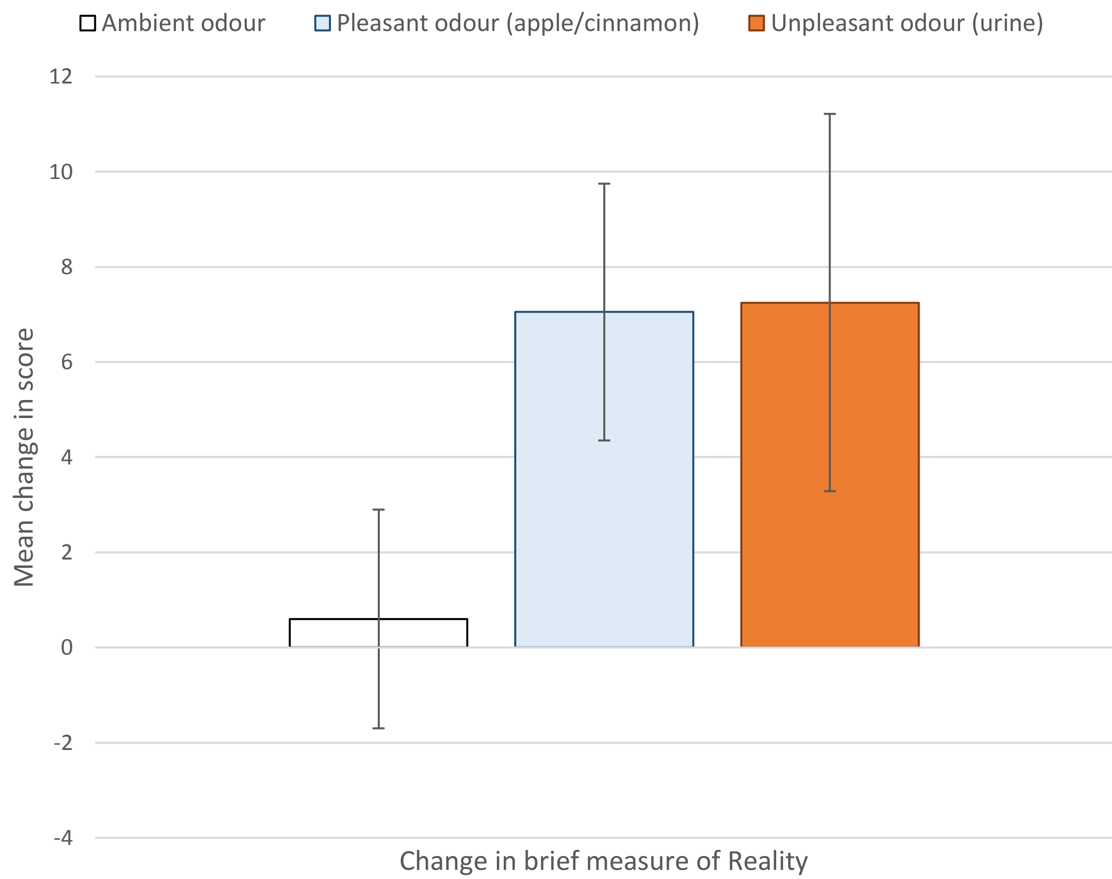

Figure 6. Illustration of the brief measure of Reality X Time interaction effect, as shown by mean change from the control to the experimental condition. Standard errors are represented in the figure by the error bars attached to each column.

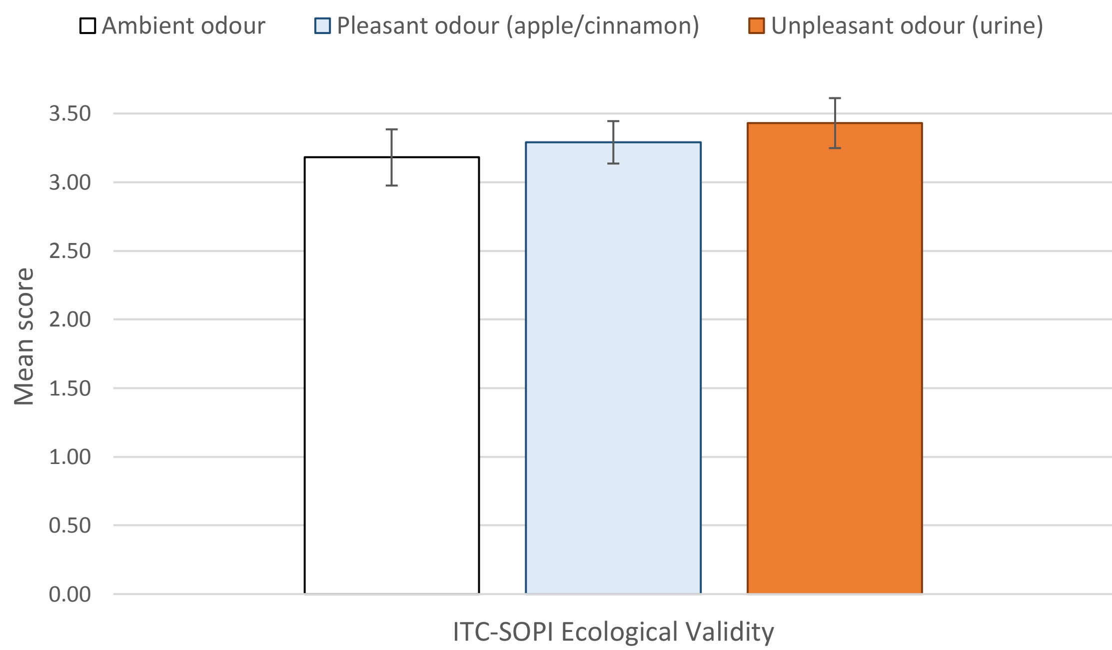

Figure 7. The sense of Realism (as measured by the Ecological Validity subscale of the ITC-SOPI). Standard errors are represented in the figure by the error bars attached to each column.

Appendix

Additional analyses

Pre-Immersion Differences Between Groups

Age. Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that the age of the AMB (*M* = 27.25; *SD* = 9.03; *Mdn* = 24.00), PLE (*M* = 26.45; *SD* = 6.98; *Mdn* = 23.50), and UNP (*M* = 24.80; *SD* = 7.83; *Mdn* = 21.50) groups did not differ in a statistically significant manner ($H(2) = 2.20$, $p = .33$).

Tendency to be immersed. The results of the one-way ANOVA confirmed that the tendency to be immersed did not differ between the AMB, PLE, and UNP groups (respectively *M* = 51.70, *SD* = 16.35; *M* = 56.95, *SD* = 16.31; *M* = 58.05, *SD* = 11.92; $F(2, 57) = 1.02$, $p = .37$, $\eta_p^2 = .04$).

Tendency to be absorbed. The results of the one-way ANOVA confirmed that the tendency to be absorbed did not differ between the AMB, PLE, and UNP groups (respectively *M* = 1.53, *SD* = .54; *M* = 1.61, *SD* = .16; *M* = 1.68, *SD* = .11; $F(2, 56) = .32$, $p = .73$, $\eta_p^2 = .01$).

Immersion-Induced Negative Side Effects

ITC-SOPI. The results of the one-way ANOVA confirmed that the levels of Negative Effect did not differ between the AMB, PLE, and UNP groups (respectively *M* = 2.02, *SD* = .73; *M* = 1.98, *SD* = .73; *M* = 2.12, *SD* = .90; $F(2,57) = .17$, $p = .84$, $\eta_p^2 = .01$).

Simulator Sickness Questionnaire. Due to the non-normal distribution of the variables, non-parametric tests were conducted. The results of a Kruskal-Wallis test indicated that, pre-immersion, cybersickness levels among the AMB (*M* = .16; *SD* = .13; *Mdn* = .13), PLE (*M* = .17; *SD* = .12; *Mdn* = .13), and UNP (*M* = .18; *SD* = .15; *Mdn* = .19) groups did not differ in a statistically significant manner ($H(2) = .28$, $p = .87$). Post-immersion, cybersickness levels among the AMB ($M = .34$; $SD = .22$; $Mdn = .28$), PLE ($M = .29$; $SD = .21$; $Mdn = .28$), and UNP ($M = .34$; $SD = .25$; $Mdn = .28$) groups also did not statistically significantly differ ($H(2) = .55$, $p = .76$). Within groups, Wilcoxon tests detected statistically significant differences between pre- and post-immersion cybersickness for the AMB ($z = -3.38$, $p = .00$, $r = -.53$), PLE ($z = -2.47$, $p = .01$, $r = -.39$), and UNP ($z = -2.92$, $p = .00$, $r = -.46$) groups. Overall, these results suggest that cybersickness levels do not differ between the groups.

Characteristics of Olfactory Stimuli Detected In Virtuo

PLE and UNP groups. The detection rates, rate of association with a memory, and presumed source of odour are shown in Table A.

Table A

Detection, Association to Memory, and Source of Odours Detected In Virtuo

Measure	Pleasant odour (cinnamon apple pie)	Unpleasant odour (urine)
Detection rate		
All participants within condition	75%	80%
Males within condition	71.43%	71.43%
Females within condition	76.92%	84.62%
Rate of association to memory	53.33%	50.00%
Participants' presumed source of odour		
Element of VE	73.33%	37.50%
Element of physical world	0%	6.25%
Imaginary source	13.33%	37.50%
Unknown	13.33%	18.75%

Comparison between the characteristics of the PLE and UNP odours. Due to the non-normal distribution within the groups and in order to compare the characteristics of the PLE and UNP odours, non-parametric comparisons were conducted. These confirmed that, as assessed by the PLE (n = 15) and UNP (n = 16) participants who detected the odour *in virtuo*, the PLE odour was statistically significantly more pleasant (*Mdn* = 5.00) than the UNP odour (*Mdn* = 1.00; U = 0.00, z = -4.84, p = .00, d = -4.39, r = -.91), more familiar (*Mdn* = 5.00) than the UNP odour (*Mdn* = 3.00; U = 33.50, z = -3.48, p = .00, d = -1.62, r = -.63), and more congruent with the visual scene (*Mdn* = 5.00) than the UNP odour (*Mdn* = 2.00; U = 10.50, z = -4.44, p = .00, d = -2.39, r = -.77). The PLE and UNP odours did not statistically significantly differ in terms of Intensity (respectively *Mdns* = 5.00 and 5.00; U = 115.50, z = -.19, p = .85, d = .11, r = .05). Mean values and standard errors are shown in Fig. A.

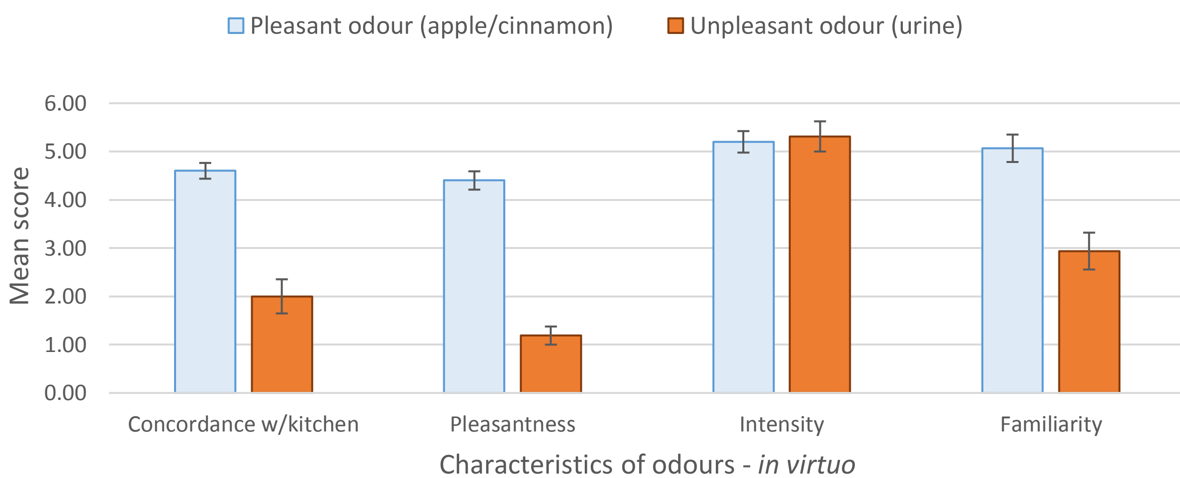

Figure A. Characteristics of olfactory stimuli presented *in virtuo*. These are based on the participants who reported having detected an odour in the kitchen (for pleasant odour, n = 15; for unpleasant odour, n =16). Standard errors are represented in the figure by the error bars attached to each column.

Characteristics of Olfactory Stimuli Detected In Vivo

PLE group. For the participants in this group, the *in vivo* detection rate of the same olfactory stimulus that they had been exposed to in the kitchen was 100% (20 out of 20). Fifteen of the group's members (75%) stated that the odour was associated with a memory.

UNP group. For the participants in this group, the *in vivo* detection rate of the same olfactory stimulus that they had been exposed to in the kitchen was 100% (20 out of 20). Sixteen of the group's members (80%) stated that the odour was associated with a memory.

Comparison between the characteristics of the PLE and UNP odours. Due to the non-normal distribution of the characteristics of the odours, and in order to compare the characteristics of the PLE and UNP odours, non-parametric comparisons were conducted. These confirmed that, as assessed by the participants in the PLE (n = 20) and UNP (n = 20) groups when they were exposed to the odour *in vivo* (post-questionnaires), the PLE odour was statistically significantly more pleasant (*Mdn* = 4.00) than the UNP odour (*Mdn* = 1.00; U = 17.00, z = -5.02, p = .00, d = -2.79, r = -.81) and more congruent (*Mdn* = 4.50) with the visual scene than the UNP odour (*Mdn* = 2.00; U = 74.00, z = -3.50, p = .00, d = -1.36, r = -.56). However, the PLE and UNP odours did not statistically significantly differ in terms of Intensity (respectively *Mdns* = 5.00 and 6.00; U = 147.00, z = -1.49, p = .14, d = .57, r = .27) or Familiarity (respectively *Mdns* = 5.00 and 4.00; U = 148.50, z = -1.43, p = .15, d = -.38, r = -.19). Mean values and standard errors are shown in Fig. B.

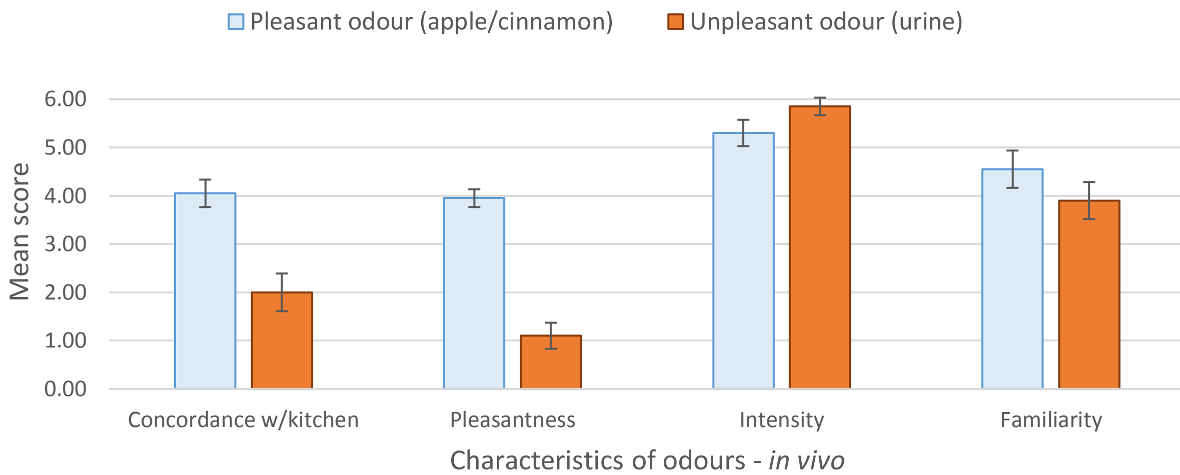

Figure B. Characteristics of olfactory stimuli presented *in vivo*. These are based on a 30-second exposure to the same stimulus that participants had been exposed to *in virtuo*. This time, however, participants had been made aware of the exposure to an olfactory stimulus (for pleasant odour, n = 20; for unpleasant odour, n = 20). Standard errors are represented in the figure by the error bars attached to each column.

Interprétation de l'ensemble des trois études

L’intérêt de ce projet était de contribuer aux connaissances sur l’utilité d’intégrer des stimuli olfactifs en RV. De manière générale, il s’agissait d’examiner les bénéfices potentiels que l’intégration de stimuli olfactifs pourrait avoir sur la qualité de l’expérience humaine en RV. Plus spécifiquement, l’objectif consistait à vérifier si, durant une immersion en RV, l’exposition à un stimulus olfactif aurait un effet sur les sentiments de présence (mesure principale), réalité et réalisme (mesures exploratoires) de l’usager.

La méthode consistait à vérifier cette relation sur trois études utilisant une condition contrôle (aucune odeur ajoutée) et deux conditions expérimentales (exposition à une odeur agréable de tarte aux pommes/cannelle ou à une odeur désagréable d’urine). Afin de réduire les biais potentiels et de procéder à l’immersion dans des conditions opérationnelles (tel que la RV serait utilisée pour des applications), les participants ne furent pas informés de l’éventuelle exposition à un stimulus olfactif. Cependant, les caractéristiques de la salle d’immersion et le protocole d’expérimentation assuraient que l’espace d’immersion était suffisamment odorisé pour rendre possible la perception (subconsciente ou consciente) du stimulus olfactif. Le type de scène visuelle différenciait les trois études. Alors que durant la première étude (Étude 1) il n’y avait pas de lien explicite entre la scène visuelle de l’EV et les odeurs, durant la seconde (Étude 2), il y avait un lien explicite (« concordance ») entre la scène visuelle et l’odeur désagréable. Durant la troisième étude (Étude 3), il y avait un lien explicite entre la scène visuelle et l’odeur agréable. Ces variations de scène visuelle avaient pour but de vérifier le lien entre l’exposition à un stimulus olfactif et le sentiment de présence dans différentes conditions de concordance entre les stimuli visuels et olfactifs.

Taux de Détection Consciente des Stimuli Olfactifs

Le premier résultat intéressant de ce projet concerne les différents taux de détection consciente des odeurs en RV. On observe que, généralement, l'odeur désagréable a été détectée plus fréquemment que l'odeur agréable (voir Fig. 1). Cette observation va dans le même sens que des résultats suggérant que la détection d'une odeur agréable peut prendre plus de temps que celle d'une odeur désagréable (Jacob & Wang, 2006). Il a été suggéré que cette différence est liée à l'importance qu'une odeur désagréable représente pour la survie (Jacob & Wang, 2006). Cependant, dans le cadre de ce projet-ci, lorsque mesurés *in vivo*, les temps de détection des odeurs agréable et désagréable ne différaient pas de manière statistiquement significative. Cette absence de différence est peut-être liée au fait que durant cette vérification (*in vivo*), les participants avaient été informés de l'exposition imminente à une odeur.

Quand on compare les différences entre les taux de détection de l'odeur agréable (groupe PLE) durant les études 1 et 3, ainsi que les différences entre les taux de détection de l'odeur

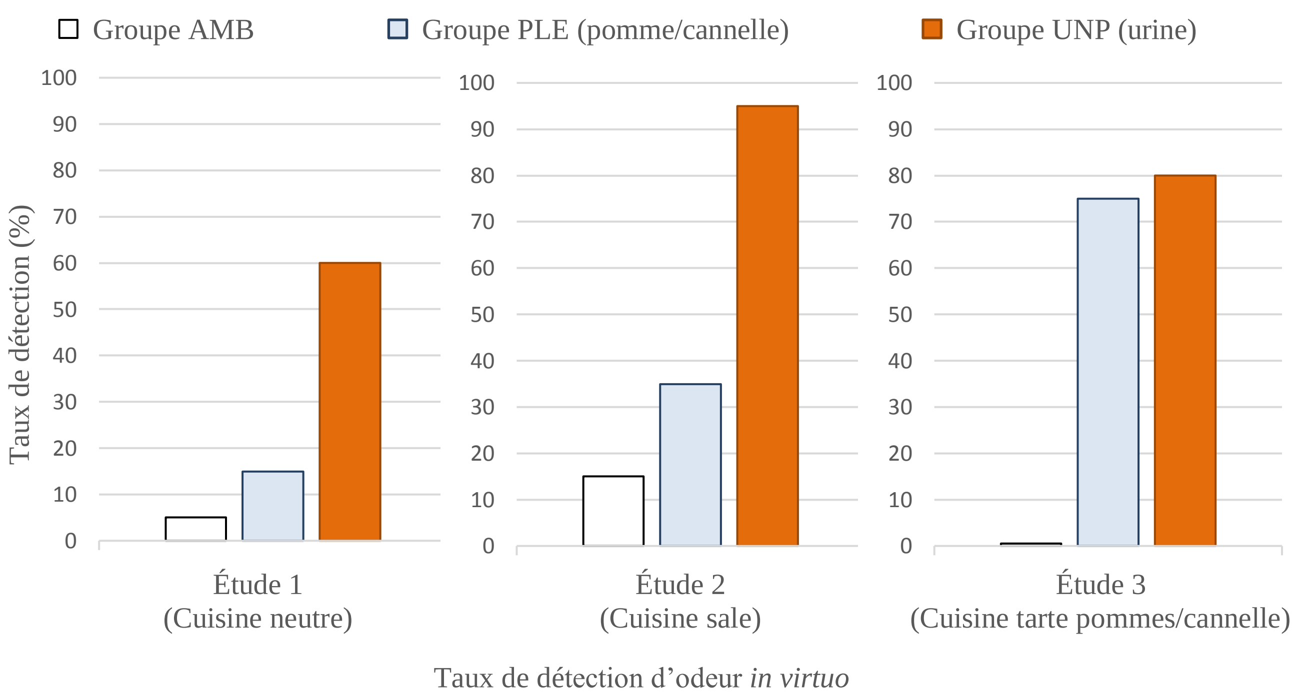

Fig. 1. Taux de détection d'odeur dans la cuisine virtuelle (études 1, 2, & 3)

désagréable (groupe UNP) durant les études 1 et 2, on observe que la concordance visuelle/olfactive semble augmenter le taux de détection consciente de chacune des odeurs en RV (voir Fig. 1). Ces résultats rejoignent ceux indiquant qu'un plus haut degré de concordance sémantique entre une image et une odeur facilite la détection de cette odeur (Gottfried & Dolan, 2003). Les résultats concernant la détection des odeurs en RV sont novateurs et ils suggèrent que, si l'objectif d'une application en EV dépendait de la détection consciente d'une odeur particulière, alors il serait prudent que l'EV inclue un ou plusieurs éléments visuels faisant le lien avec cette odeur.

Le Sentiment de Présence

Questionnaire de présence – Un item. L'intérêt de cette mesure repose sur son faible degré d'invasion, permettant ainsi de multiples prises de mesure durant immersion.

Effet de l'odeur agréable sur le sentiment de présence. Ni la première ni la deuxième étude n'ont permis de détecter de différence de présence entre le groupe exposé à l'odeur agréable et celui exposé à l'odeur ambiante (voir Fig. 2). Par contre, il semblait possible que ces résultats aient été liés au taux extrêmement faible de détection consciente *in virtuo* de l'odeur agréable (respectivement, 15% et 35%). Toutefois, malgré un taux de détection consciente de 75%, la troisième étude n'a, elle non plus, pas détecté de différence statistiquement significative en présence entre le groupe exposé à l'odeur agréable et le groupe contrôle (voir Fig. 2). Cependant, durant l'Étude 3, le sentiment de présence du groupe exposé à l'odeur agréable avait, en fait, augmenté de manière manifeste de la chambre à coucher à la cuisine. Par contre, à la différence des deux premières études, le sentiment de présence du groupe contrôle avait également augmenté de manière statistiquement significative d'une pièce à l'autre. Cette augmentation a possiblement contribué à l'absence d'une différence statistiquement significative entre les groupes AMB et PLE.

Effet de l'odeur désagréable sur le sentiment de présence. Les deux premières études ont révélé des différences statistiquement significatives de l'augmentation du sentiment de présence entre les groupes exposés à l'odeur désagréable et les groupes contrôles respectifs (voir Fig. 2). Par contre, ceci ne fut pas le cas pour l'Étude 3 et cela, malgré une augmentation du sentiment de présence du groupe exposé à l'odeur désagréable (voir Fig. 2). En effet, la hausse inattendue de présence du groupe contrôle a probablement contribué à maintenir la différence entre les groupes UNP et AMB statistiquement non significative.

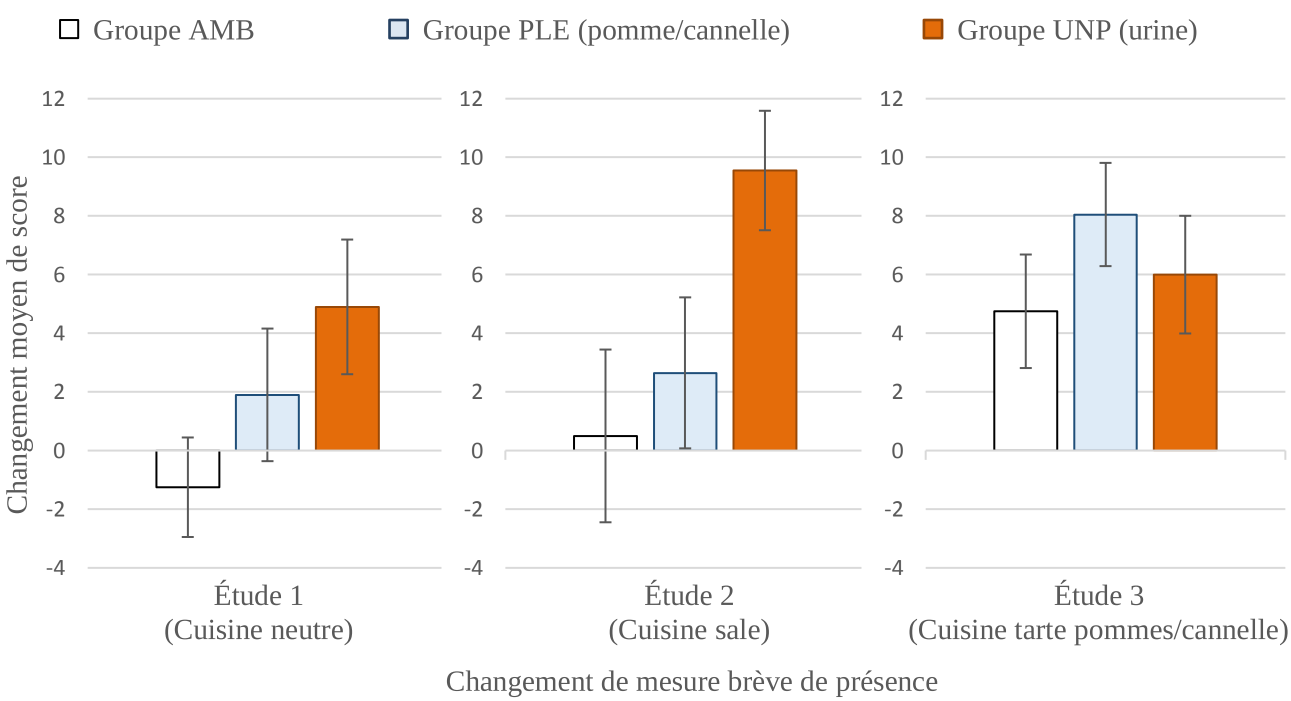

Fig. 2. Changement du degré de présence de la chambre à coucher à la cuisine – Questionnaire à un item (études 1, 2, & 3)

Sommaire. Les résultats des deux premières études suggèrent que dans des EV visuels neutre ou concordant avec l'odeur désagréable, l'exposition à une odeur désagréable peut mener à une augmentation du sentiment de présence. Étonnamment, dans le cas d'un environnement visuel concordant une odeur agréable, ni l'exposition à l'odeur agréable ni celle à l'odeur désagréable, n'a produit de différence statistiquement significative avec le groupe contrôle. Le comportement du groupe contrôle de l'Étude 3 fournit peut-être un indice pour expliquer ces résultats. En effet, à la différence des groupes contrôles des études 1 et 2, celui de l'Étude 3 a rapporté un sentiment de présence statistiquement plus élevé dans la cuisine que dans la chambre à coucher. Cette différence surprend d'autant plus que les trois études ont suivi un protocole commun, sauf pour les éléments visuels dans la cuisine (ainsi que les participants et la saison de passation du protocole). Les éléments visuels de la cuisine (tartes aux pommes, ingrédients et ustensiles requis pour préparer des tartes aux pommes) ont possiblement mené à cette augmentation du sentiment de présence. Si cela a vraiment été le cas, alors cet effet aurait dû affecter les groupes expérimentaux également. Compte tenu des résultats des deux premières études, on peut se demander si l'effet de la scène visuelle sur la présence aurait, en quelque sorte, noyé l'effet des odeurs. Afin de vérifier cette hypothèse, on pourrait reproduire cette étude avec quatre conditions : (a) cuisine neutre sans aucun stimulus olfactif ajouté; (b) cuisine neutre avec stimulus olfactif « Grand-Ma's kitchen »; (c) cuisine neutre avec stimulus olfactif « urine »; (d) cuisine « tartes aux pommes » sans aucun stimulus olfactif ajouté; (e) cuisine « tarte aux pommes » avec stimulus olfactif « Grand-Ma's kitchen.»; et (f) cuisine « tarte aux pommes » avec stimulus olfactif « urine ». Ainsi, on pourrait quantifier l'effet du type de scène visuelle, celui du type d'odeur, ainsi que celui de leur interaction sur le sentiment de présence.

Questionnaire de présence – ITC-SOPI. L'intérêt du questionnaire repose sur sa validité bien établie.

Effet de l'odeur agréable sur le sentiment de présence. Aucune des études n'a permis de détecter de différence entre les degrés de présence des groupes exposés à l'odeur agréable et les degrés de présence des groupes contrôles respectifs (voir Fig. 3). On peut quand même noter que, dans l'EV neutre, malgré un taux de détection consciente très bas, la différence avec le groupe contrôle fut très proche d'être statistiquement significative.

Effet de l'odeur désagréable sur le sentiment de présence. Dans chacune des études, le sentiment de présence du groupe exposé à l'odeur désagréable a été plus élevé que celui des groupes contrôles respectifs. Cependant, cette différence a atteint le seuil de signification statistique uniquement dans l'EV neutre (voir Fig. 3).

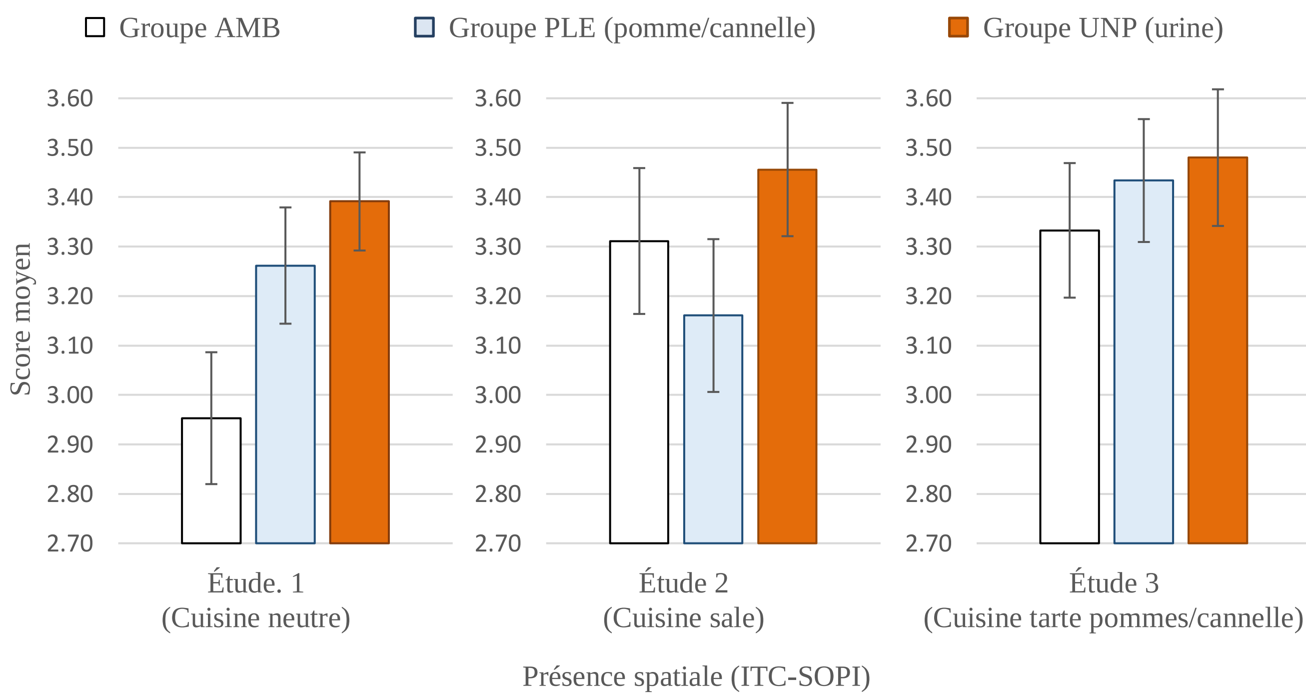

Fig. 3. Degré de présence – Sous-échelle de présence spatiale du ITC-SOPI (études 1, 2, & 3)

Sommaire. Autre que pour les résultats du groupe UNP durant l'Étude 1, les résultats tirés de la sous-échelle présence spatiale de l'ITC-SOPI n'ont pas donné de différence statistiquement significative entre les groupes contrôles et les groupes expérimentaux. Et cela, malgré des moyens importants mis en œuvre pour tenter de contrôler les différences individuelles. On peut quand même noter qu'aucun des résultats liés à l'ITC-SOPI ne contredit ceux des mesures de présence à un item.

Le Sentiment de Réalité

Effet de l'odeur agréable sur le sentiment de réalité. Même si l'augmentation du sentiment de réalité des groupes PLE a été supérieure à celle des groupes AMB pour chacune des études, cette augmentation n'a été statistiquement significative que lorsque l'odeur agréable concordait avec l'EV, c'est-à-dire durant l'Étude 3 (voir Fig. 4).

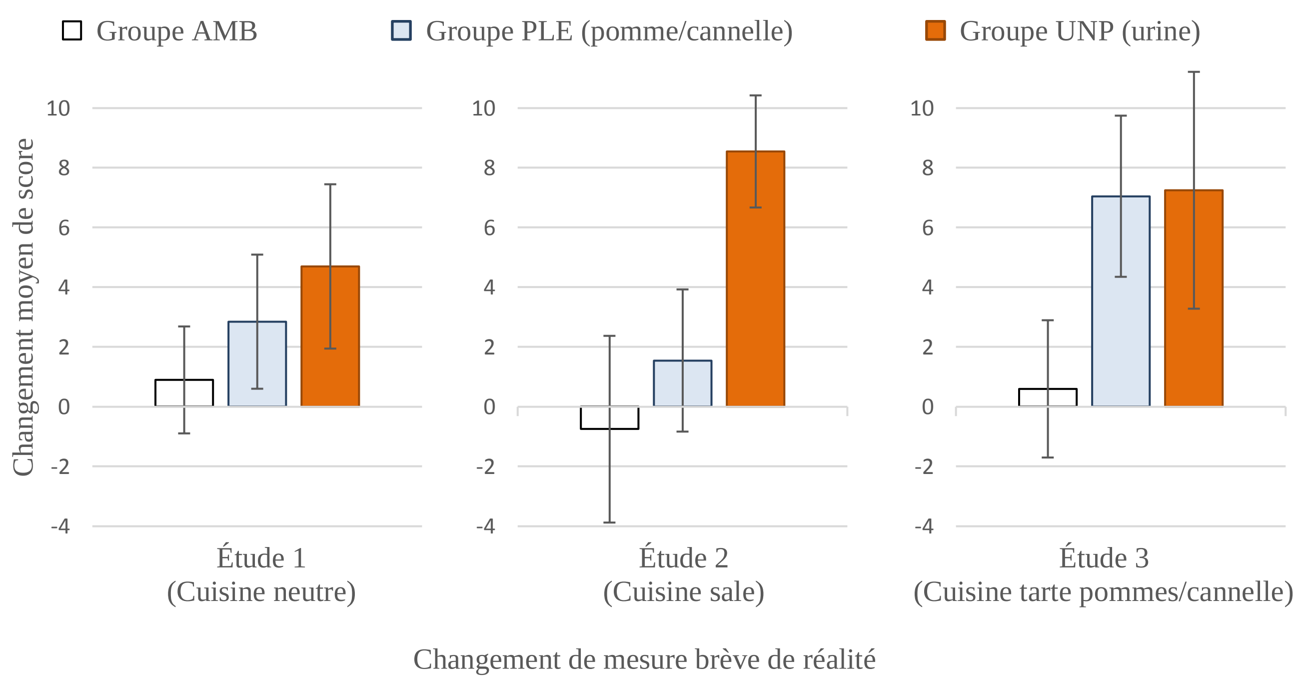

Fig. 4. Changement du degré de réalité de la chambre à coucher à la cuisine – Questionnaire à un item (études 1, 2, & 3)

Effet de l'odeur désagréable sur le sentiment de réalité. L'augmentation du sentiment de réalité des groupes UNP a également été supérieure à celle des groupes AMB pour chacune des études, mais l'augmentation n'a été statistiquement significative que lorsque l'odeur désagréable concordait avec l'EV, c'est-à-dire durant l'Étude 2 (voir Fig. 4). Cependant, l'exposition à l'odeur désagréable était très proche d'avoir un effet statistiquement significatif sur le sentiment de réalité durant l'Étude 3.

Sommaire. Les résultats statistiquement significatifs suggèrent que l'exposition à une odeur augmente le sentiment de réalité dans des conditions de concordance visuelle et olfactive. Pour chacune des études, la forme du diagramme en bâtons concernant le changement de réalité (Fig. 4) ressemble à celle de diagramme en bâtons concernant les taux de détection des odeurs (Fig. 1); cette similitude pourrait indiquer une corrélation entre la détection d'un stimulus olfactif et le sentiment de réalité en RV. Autrement dit, il se peut que le simple fait de détecter une odeur fasse augmenter le degré de réalité. Cette hypothèse demande à être vérifiée.

Le Sentiment de Réalisme

Effet de l'odeur agréable sur le sentiment de réalisme. À travers des trois études, l'exposition à l'odeur agréable n'a mené à aucune différence statistiquement significative entre les groupes PLE et les leur groupe contrôle respectif.

Effet de l'odeur désagréable sur le sentiment de réalisme. Malgré le fait que les scores de réalisme des groupes UNP aient surpassé ceux des groupes contrôles respectifs dans chacune des études, la différence n'a été statistiquement significative que lorsque la scène visuelle concordait avec l'odeur (Étude 2).

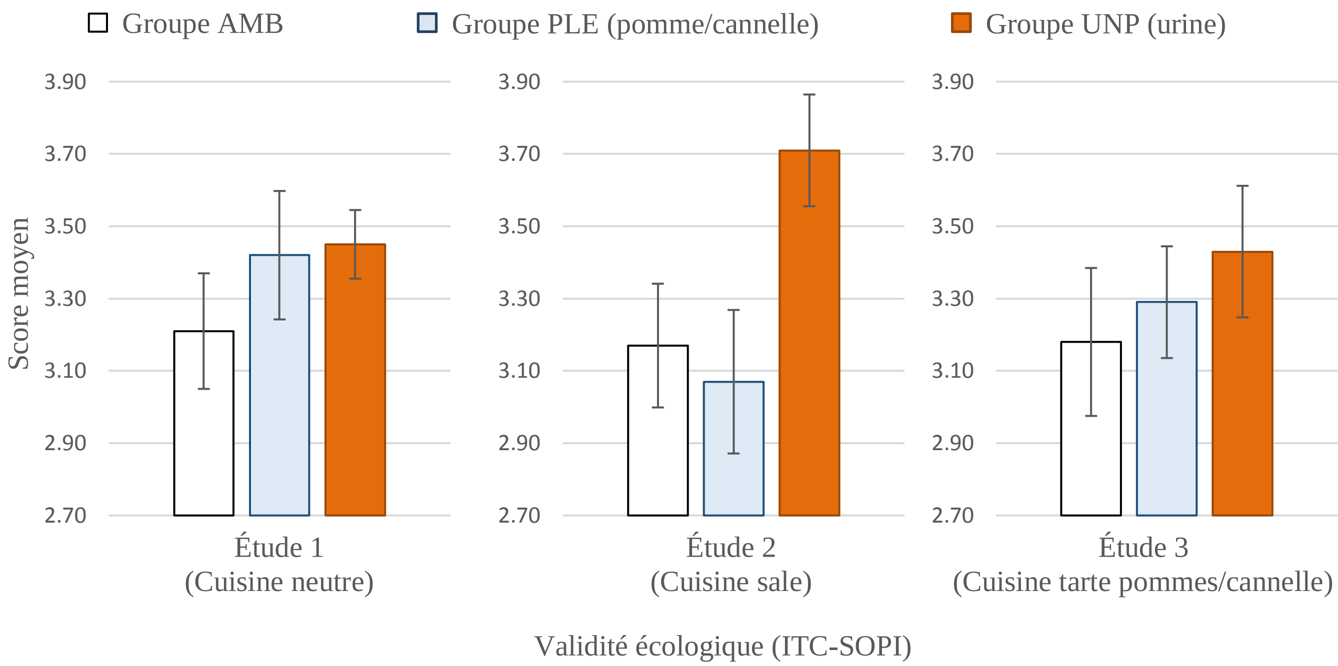

Fig. 5. Degré de réalisme – Sous-échelle de validité écologique du ITC-SOPI (études 1, 2, & 3)

Sommaire. Dans un EV neutre (Étude 1), les degrés de réalisme des groupes expérimentaux ont surpassé celui du groupe contrôle, mais pas de manière statistiquement significative. Lors d'une concordance entre l'EV et l'odeur désagréable (Étude 2), le degré de réalisme du groupe UNP a dépassé celui du groupe contrôle de manière statistiquement significative. Ceci n'a pas été le cas pour le groupe PLE lorsque l'odeur agréable concordait avec l'EV (Étude 3).

Limites

Limites Liées aux Mesures de Variables Concernant la Qualité de l'Expérience en RV

Le sentiment de présence. Une des limites de ce projet concerne le compromis qui a dû être fait vis-à-vis de la mesure du sentiment de présence. Plusieurs facteurs liés au sentiment de présence justifiaient l'utilisation d'un questionnaire complété durant l'immersion et à mesures répétées (c'est-à-dire à dire dans la chambre à coucher, ensuite dans la cuisine, et inversement).

Ces facteurs incluent : (a) le sentiment de présence est un concept nouveau pour les participants, il serait donc prudent de le mesurer via plusieurs questions; (b) le sentiment de présence est un phénomène qui se ressent durant une immersion; (c) un questionnaire post-immersion risque d'être sujet à des biais de rappel; et (d) un grand nombre de facteurs individuels peuvent influer sur le sentiment de présence. Cependant, il était également préférable de limiter le nombre de questions durant immersion, car : (a) un grand nombre de questions posées durant l'immersion risquait de « briser » le sentiment de présence; et (b) une longue immersion risquait d'augmenter le degré de cybermalaises. Conséquemment, un compromis a été fait en utilisant : (a) durant l'immersion, des mesures répétées à un item; et (b) post-immersion, un questionnaire complémenté par des mesures tentant de contrôler les différences individuelles. Chacune de ces deux méthodes de mesure avait pour limites certains des facteurs ci-dessus.

Le sentiment de réalisme. Il aurait été souhaitable d'également mesurer le sentiment de réalisme par le biais des mesures brèves à un item, prises en mesures répétées durant l'immersion. Cependant, il a été jugé que, dû aux similarités phonétique et sémantique des sentiments de réalité et réalisme, les participants risquaient de ne pas bien faire les différencier durant l'immersion. Il a donc été décidé de mesurer le sentiment de réalisme par questionnaire, post-immersion. Par contre, cela aura nui à la puissance des analyses concernant le sentiment de réalisme.

Limites Liées aux Odeurs

Les caractéristiques des odeurs. La nature même des stimuli olfactifs a imposé certaines limites à ce projet. À la différence d'une image que l'on peut faire apparaitre et disparaitre rapidement et à volonté, un stimulus olfactif, une fois « projeté » dans l'environnement, devient difficile à contrôler. Interrompue à sa source, une odeur ne disparait pas immédiatement, mais tend à s'estomper petit à petit. Le laboratoire de recherche n'étant pas équipé d'un système de ventilation permettant d'évacuer rapidement et silencieusement les odeurs durant une immersion, le protocole à mesures répétées se limitait à exposer les participants aux odeurs dans la dernière pièce de l'immersion. Il n'a donc pas été possible de contrôler l'effet de l'ordre des pièces. De plus, il aurait été préférable de pouvoir utiliser plus qu'un stimulus olfactif par immersion; cela n'a pas été possible.

Le faible taux de détection consciente de l'odeur agréable (études 1 et 2). Les différences importantes entre les taux de perception consciente des odeurs agréable et désagréable limitent quelque peu les conclusions concernant l'effet de l'exposition à une odeur agréable dans des EV neutre et discordant avec l'odeur. En effet, il reste incertain si cette absence d'effet était plutôt liée aux caractéristiques de l'odeur, et/ou au degré très bas de perception.

Interaction potentielle entre scénario anxiogène et détection des odeurs. Afin de favoriser l'immersion, un scénario quelque peu anxiogène a été utilisé pour les études. Hors, les résultats de certaines études suggèrent que l'état émotionnel, surtout les émotions négatives, peuvent réduire la sensibilité olfactive (p. ex., Chen, & Dalton, 2005; Pollatos et al., 2007). Une étude récente (Takahashi et al., 2015) ayant exposé des participants à trois odeurs agréables (la rose, le caramel et le fruit sucré) et deux odeurs désagréables (la nourriture pourrie et la matière fécale) a trouvé que l'anxiété était liée à une réduction des capacités olfactives, et surtout à une réduction du taux d'identification d'une des odeurs agréables utilisées, l'odeur de la rose. On peut donc se demander si le scénario anxiogène aurait pu engendrer une plus grande réduction de la sensibilité à l'odeur de pommes/cannelle qu'à celle de l'urine. Le cas échéant, cela aurait pu contribuer aux différences, parfois importantes, entre les taux de perception des odeurs agréables et désagréables en RV.

Conclusions générales et recommandations

Bien que les résultats de ce projet ne fournissent pas de réponse simple et tranchée à la question sur l'effet de l'exposition aux stimuli olfactifs sur le sentiment de présence en RV, il est possible d'en tirer quelques conclusions et tendances. Tout d'abord, les résultats suggèrent qu'en RV : (a) l'odeur désagréable se détecte plus facilement qu'une odeur agréable; et (b) la concordance visuelle/olfactive peut augmenter le taux de détection d'une odeur agréable, ainsi que celui d'une odeur désagréable. L'intérêt de ses résultats réside dans la possibilité de les prendre en compte dans le développement d'applications dont l'effet dépend de, ou est amélioré par, la détection d'une odeur. En particulier, pour les applications pouvant bénéficier de la détection consciente d'une odeur agréable (p. ex., House of Relaxation; Serrano et al., 2016), les développeurs pourraient adapter les scènes visuelles afin de créer une concordance visuelle/olfactive aux odeurs de choix.

En ce qui concerne la qualité de l'expérience en RV, l'intégration de stimuli olfactifs en RV peut bénéficier les sentiments de présence et de réalité, mais la détection consciente de l'odeur semble jouer un rôle dans ces relations. Effectivement, lorsque le taux de détection consciente restait en dessous de 60%, ni le sentiment de présence, celui de réalité ou celui de réalité n'ont été affectés par l'exposition à une odeur. Dans le cadre d'un EV virtuel de concordance neutre (taux de détection de 60%) et d'un EV concordant avec l'odeur désagréable (taux de détection de 95%), l'exposition à l'odeur désagréable a augmenté le sentiment de présence de manière statistiquement significative. Quant au sentiment de réalité, il a augmenté lors de l'exposition à l'odeur agréable et concordante avec l'EV (taux de détection de 75%), ainsi que lors de l'exposition à l'odeur désagréable et concordante avec l'EV (taux de détection de 95%). Les résultats les plus probants ont été enregistrés lorsque l'EV concordait avec l'odeur désagréable : dans cette situation, le taux de détection a atteint 95% et l'exposition à l'odeur a affecté chacun des sens de présence, de réalité et de réalisme. Ces résultats sont d'intérêt pour le développement d'applications visant à faire vivre à l'usager une expérience plus immersive (p. ex., des applications visant à traiter l'agoraphobie ou des applications dans le domaine du divertissement).

Il semble donc que malgré l'effet que peuvent avoir des odeurs subliminales sur certains processus cognitifs et physiologiques (p. ex., amabilité sociale, réponses autonomiques; Li et al., 2007), une odeur doit être perçue consciemment pour influer sur le sentiment de présence en RV. Une odeur distinctive de celle de l'environnement physique, une fois perçue, contribuerait à former l'illusion perceptuelle de la non-médiation, telle que décrite par Lombard et Ditton (1997). D'un point de vue olfactif, le « départ » du monde physique et « l'arrivée » dans le monde virtuel décrits par Biocca et Kim (1997) sembleraient avoir lieu si l'odeur est perçue consciemment. Jusqu'à maintenant, la question de l'influence des stimuli olfactifs sur la qualité de l'expérience en RV s'était posée en termes d'exposition : soit la perception de l'odeur était quasi-certaine (p. ex., via l'utilisation d'un masque à oxygène; Dinh et al., 1999), soit la perception de l'odeur était prise pour acquise et pas vérifiée (p. ex, Serrano et al., 2016). Les résultats du présent projet suggèrent que, même si l'exposition aux odeurs bonifie les qualités immersives d'un EV, son effet sur le sentiment de présence n'a pas lieu si l'usager de la RV n'est pas conscient de l'odeur.

Il reste cependant plusieurs zones d'ombre à éclaircir dans la relation entre un stimulus olfactif et la qualité de l'expérience en RV et il serait utile de continuer cette ligne d'investigation. Afin de vérifier si le bas taux de perception de l'odeur agréable a effectivement joué un rôle important dans l'absence d'effet sur le sentiment de présence, il pourrait être utile de concevoir un protocole quasi expérimental qui grouperait les participants, non pas selon qu'ils aient été exposés ou pas à l'odeur agréable, mais selon qu'ils aient perçu, ou pas, l'odeur agréable. De plus, compte tenu des résultats contre-intuitifs de l'Étude 3 (en particulier, le comportement du groupe contrôle), il pourrait être utile de la répéter, mais cette fois-ci, avec deux variables indépendantes : la scène visuelle (neutre ou « tartes aux pommelles/cannelle ») et l'exposition à un stimulus olfactif (ambiant, agréable - tartes aux pommes/cannelle, désagréable - urine). Ceci permettrait de quantifier l'effet de l'exposition à chacune des odeurs, l'effet de la scène visuelle dans la cuisine ainsi que l'effet des interactions. Compte tenu du grand nombre de variables individuelles pouvant influencer le sentiment de présence, et tel que suggéré par Jones et collègues (2004), l'usage de mesures répétées serait privilégié pour ces éventuels projets.

Une des spécificités de ce projet est qu'il a été complété dans des conditions qui, d'une part, ne laissaient pas soupçonner l'utilisation de stimuli olfactifs et d'autre part, laissaient vérifier leur taux de perception *in virtuo*. Cette méthodologie a permis de révéler que l'intégration de stimuli olfactifs peut augmenter le sentiment de présence en RV, mais que des mesures devraient être prises pour maximiser la probabilité que les odeurs d'intérêt soient consciemment perçues par l'usager.

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Annexe A : Formulaires de consentement

Formulaire de consentement

Titre du projet :	Les sentiments de présence et de réalité dans un environnement virtuel
Étudiant chercheur :	Oliver Baus Tél : (819) 595-3900, poste 2528
Directeur de recherche :	Stéphane Bouchard, Ph.D. Université du Québec en Outaouais Dept. de Psychoéducation et de psychologie CP 1250, Succ Hull, Gatineau, Qc. J8X 3X7. Canada Courriel : Stephane.Bouchard@uqo.ca Tél : (819) 595-3900, poste 2360

Général

Par la présente, nous sollicitons votre participation à la recherche en titre. Cette dernière vise à mieux comprendre la relation entre les détails de l'image d'un environnement virtuel et les sentiments de présence et de réalité.

Alors que le sentiment de présence peut être défini comme la perception d'être présent (ou d'exister) dans un environnement virtuel, le sentiment de réalité fait référence au sentiment que votre expérience dans l'environnement virtuel est réelle.

Nature et durée de la participation au projet de recherche

L'étude aura lieu au Laboratoire de Cyberpsychologie de l'UQO (Local C-2500, 283 Boul. A.-Taché, Secteur Hull), et votre participation prendra la forme d'une seule rencontre avec le chercheur.

Lors de cette rencontre, le chercheur vous expliquera les procédures à suivre lors de l'expérimentation et le fonctionnement de l'équipement. Vous serez ensuite invité(e) à vous immerger dans un appartement virtuel où on vous demandera de vous déplacer dans différentes pièces. Chacune de ces pièces (salle de bain, salon, bureau, chambre à coucher et cuisine/salle à manger) sera représentée par un niveau de détail visuel quelque peu différent. Vous serez invité(e) à vous déplacer à l'intérieur de chacune de ces pièces pendant une minute, après quoi, on vous demandera d'évaluer verbalement vos degrés de présence et de réalité.

Durant l'immersion nous enregistrerons votre rythme cardiaque et votre conductance électrodermique. Le rythme cardiaque correspond au nombre de battements de cœur par minute. Le rythme cardiaque est capté par une ceinture du type T31 Polar qui envoie, sans fil, les mesures cardiaques à un récepteur EKG attaché à la ceinture, qui lui, transmet l'information à l'encodeur ProComp Infiniti par l'entremise d'un câble. L'encodeur, porté dans un sac banane autour de la taille du participant, envoie, par le biais d'un transmetteur Bluetooth Tele-Infiniti CF, les données à un ordinateur exécutant le logiciel Biograph Infiniti. La conductance électrodermique correspond à l'habileté d'un courant électrique à circuler dans le corps humain. Plus spécifiquement, certaines variables psychologiques et environnementales peuvent mener à une augmentation de l'hydratation des glandes sudoripares, permettant ainsi à l'électricité de mieux circuler. Afin de la mesurer, deux capteurs de conductance électrodermique sont placés au bout de l'index et de l'annulaire de la main non dominante du participant. Ces capteurs sont branchés, par câble, à l'encodeur ProComp Infiniti, puis sans fil à l'ordinateur exécutant le logiciel Biograph Infiniti.

Une fois que vous aurez donné vos cotes de présence et de réalité dans la dernière pièce (la cuisine/salle à manger), vous serez invité(e) à enlever le visiocasque et à remplir quelques questionnaires reliés à votre expérience en réalité virtuelle. L'immersion en réalité virtuelle est d'une durée approximative de 10 minutes.

Cette rencontre, dont environ 10 minutes seront passées dans l'environnement virtuel, durera approximativement 90 minutes.

Confidentialité des données

Les données recueillies dans cette étude sont entièrement confidentielles et ne pourront, en aucun cas, mener à votre identification. Votre confidentialité sera assurée, puisque tous les questionnaires seront identifiés à l'aide d'un code alphanumérique. Les résultats seront diffusés dans un travail de thèse de doctorat (possiblement aussi dans des publications scientifiques et des conférences); une identification des participants ne sera pas possible. Les données recueillies seront conservées sous clé dans un classeur à l'Université du Québec en Outaouais. Les seules personnes qui y auront accès sont le chercheur (Oliver Baus), le directeur de recherche (Stéphane Bouchard) et la coordonnatrice des projets de recherche (Geneviève Robillard). Elles seront détruites dans cinq ans, et ne seront pas utilisées à d'autres fins que celles décrites dans le présent document.

Inconvénients et avantages et de la participation

Les inconvénients de ce projet de recherche sont en lien avec un certain risque d'inconfort, mais le chercheur s'engage à mettre en œuvre les moyens nécessaires pour les réduire ou les pallier.

En effet, lorsque vous serez immergé dans l'environnement représentant l'appartement, il est possible de ressentir des malaises pendant ou après l'exposition virtuelle. Ces symptômes sont temporaires et peuvent impliquer une fatigue visuelle, une vision embrouillée ou des maux de tête. Ces effets se dissipent généralement au fur et à mesure que le cerveau s'habitue à l'équipement et l'environnement virtuel. Si ces malaises deviennent trop inconfortables pour vous, vous pourrez cesser la séance en tout temps. Vous devrez attendre une quinzaine de minutes avant de quitter le laboratoire; ce délai assurera que vous ne ressentez pas d'effets secondaires suite à l'exposition virtuelle. Le seul inconvénient certain à participer à cette étude est le temps que vous y accorderez, soit environ 90 minutes à l'UQO.

La participation à cette recherche vous offre le bénéfice de faire l'expérience de la réalité virtuelle, un domaine qui, dans un futur proche, risque fort d'avoir un impact majeur sur de nombreuses facettes de la vie humaine (éducation, réhabilitation, divertissement, etc.). De plus, en participant à cette étude, vous contribuez à l'avancement des connaissances au sujet de l'expérience humaine en réalité virtuelle. Aucune compensation d'ordre monétaire n'est accordée.

Personnes ressources

Si vous avez des questions concernant ce projet de recherche, communiquez avec l'étudiant chercheur, Oliver Baus (819) 595-3900, poste 2528, ou le directeur de recherche, Stéphane Bouchard (819) 595-3900, poste 2360.

Si après avoir quitté le laboratoire, vous ressentez des effets que vous croyez liés à votre immersion, veuillez communiquer avec Madame Geneviève Robillard, coordonnatrice des projets de recherche du Laboratoire de Cyberpsychologie, au (819) 595-3900, poste 2531.

Si vous avez des questions concernant les aspects éthiques de ce projet, communiquez avec André Durivage au (819) 595-3900, poste 1781, président du Comité d'éthique de la recherche de l'Université du Québec en Outaouais ou le bureau d'éthique et d'intégrité de la recherche de l'Université d'Ottawa au (613) 562-5387.

Consentement éclairé

Votre participation à cette étude se fait sur une base volontaire. Vous êtes entièrement libre de participer ou non, et de vous retirer en tout temps sans préjudice. Toutefois, si vous vous retirez de l'étude, vos données seront tout de même conservées pendant cinq ans.

Votre signature atteste que vous avez clairement compris les renseignements concernant votre participation au projet de recherche et indique que vous acceptez d'y participer. Elle ne signifie pas que vous acceptez d'aliéner vos droits et de libérer les chercheurs ou les responsables de leurs responsabilités juridiques ou professionnelles. Vous êtes libre de vous retirer en tout temps de l'étude sans préjudice. Votre participation devant être aussi éclairée que votre décision initiale de participer au projet, vous devez en connaître tous les tenants et aboutissants au cours du déroulement de la recherche. En conséquence, vous ne devrez jamais hésiter à demander des éclaircissements ou de nouveaux renseignements au cours du projet.

Afin de préserver vos données personnelles et votre identité, les données seront anonymisées, c'est-à-dire qu'il ne sera plus possible à quiconque de pouvoir les relier à votre identité. Nous nous engageons à respecter les mêmes règles d'éthique que pour le présent projet.

Après avoir pris connaissance des renseignements concernant ma participation à ce projet de recherche, j'appose ma signature signifiant que j'accepte librement d'y participer. Le formulaire est signé en deux exemplaires et j'en conserve une copie.

Nom du participant : ______________________

Signature du participant : ______________________ Date : ____________

Nom de l'étudiant/chercheur : Oliver Baus

Signature de l'étudiant/chercheur : ______________________ Date : ____________

Nom du directeur de recherche : Stéphane Bouchard, Ph.D.

Signature du directeur de recherche : ______________________ Date : ____________

Cette recherche est financée par la Chaire de Recherche en Cyberpsychologie Clinique et a été approuvée par les Comités d'Éthique et de la Recherche de l'Université Ottawa et de l'UQO.

Formulaire de consentement – Post-expérimentation

Titre du projet : Les sentiments de présence et de réalité dans un environnement virtuel

Étudiant chercheur : Oliver Baus.

Directeur de recherche : Stéphane Bouchard, Ph.D, Département de psychoéducation et psychologie.

Dévoilement du but exact de la recherche

Par la présente, je confirme que le chercheur m'a informé que le but réel de la recherche était de vérifier le lien entre les stimuli olfactifs et le sentiment de présence. Je comprends que ceci ne m'avait pas été révélé auparavant afin d'éviter que cette information influence mes réponses aux divers questionnaires.

J'appose ma signature ci-dessous pour confirmer que je consens tout de même à ce que les données collectées durant cette expérience soient utilisées dans le cadre de ce projet de recherche. Le formulaire est signé en deux exemplaires et j'en conserve une copie.

Nom du participant : ________________________

Signature du participant : ________________________ Date : _____________

Nom de l'étudiant/chercheur : Oliver Baus

Signature de l'étudiant/chercheur : ________________________ Date : _____________

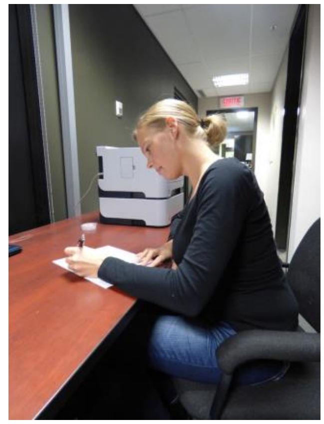
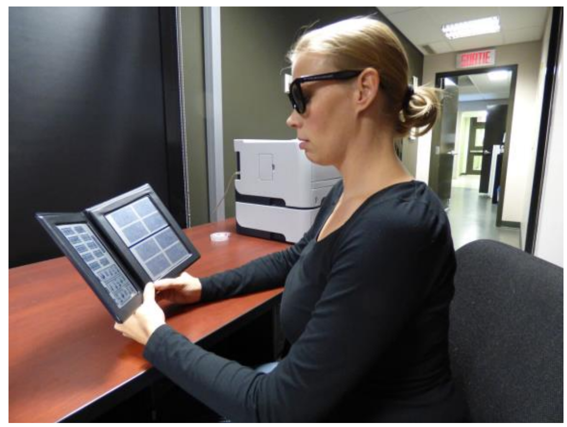
Nom du directeur de recherche : Stéphane Bouchard, Ph.D.

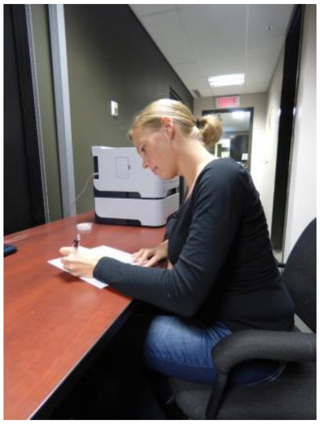
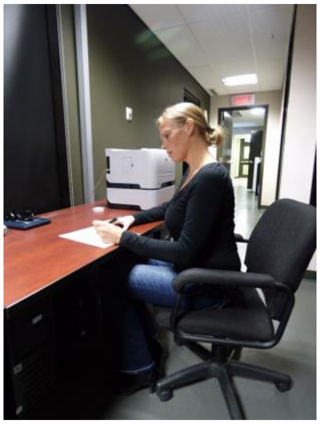
Signature du directeur de recherche : ________________________ Date : _____________

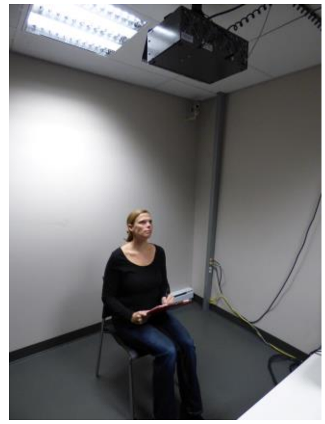
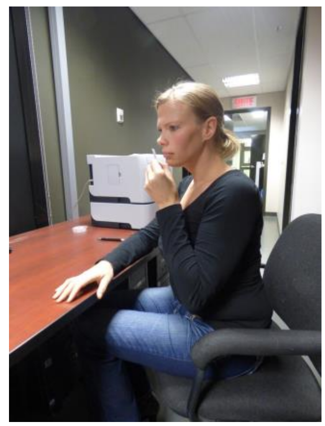
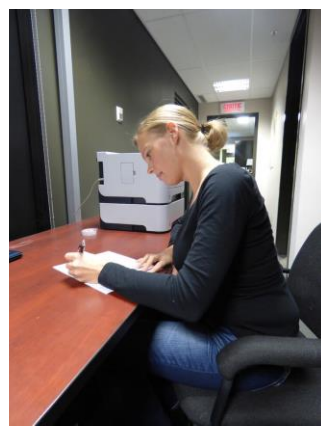
Cette recherche est financée par la Chaire de Recherche en Cyberpsychologie Clinique et a été approuvée par les Comités d'Éthique et de la Recherche de l'Université Ottawa et de l'UQO.

Annexe B : Illustration du protocole

Illustration du protocole

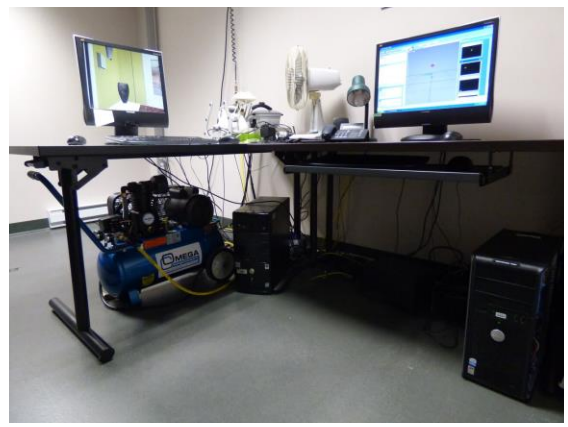
Formulaires de consentement (pré)	
Vérification de vision stéréoscopique Randot Stereotest	
Mesure de distance interpupillaire Topcon PD-5	

Questionnaires préimmersion Renseignements généraux Propension à l'immersion Échelle d'absorption de Tellegen Modifiée Cybermalaise	
Immersion Mesure verbale de présence Mesure verbale de réalité	
Questionnaires post-immersion ITC-SOPI Contre vérification de la manipulation Cybermalaise	

Exposition *in vivo* au stimulus olfactif Vérification des dimensions des odeurs	
Test d'olfaction Quick Smell Identification Test	
Formulaire de consentement (post)	

Annexe C : Matériel

Matériel

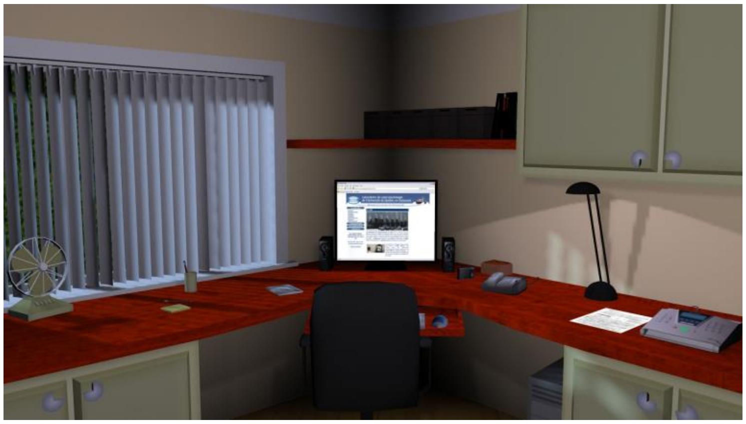
Salle d'immersion	
Matériel informatique et compresseur Intel Core2 Quad CPU Q9650 Serveur périphérique (Intel 2140) Compresseur Omega	
Visiocasque nVisor SX60 HMD Intersense InertiaCube3	

Machine à odeur (extérieur) SDS100 Scent Palette	
Machine à odeur (intérieur) SDS100 Scent Palette Cartouche à odeur (dans compartiment No.1)	

Annexe D : Environnement virtuel

Environnement virtuel

Hall d'entrée (vue sur la porte d'entrée de l'appartement)	
Couloir (tel que vu du salon)	
Salle de bain	

Salon	
Bureau	
Chambre à coucher	

Cuisine (Article 2)	
Cuisine (Article 3)	
Cuisine (Article 4)	

Annexe E : Questionnaires préimmersion

Questionnaire de renseignements généraux

No ID : ________ Date: ____________

Instructions : Veuillez répondre aux questions ci-dessous, soit en inscrivant la réponse (questions 1 & 2), soit en marquant d'un « X » la réponse appropriée (questions 3 à 7).

1. Âge : ______

2. Sexe : _____

3. Pays de naissance : ___ Canada
   ___ Autre

4. Culture dominante (par continent) : ___ Amérique du Nord
   ___ Amérique du Sud
   ___ Europe
   ___ Afrique
   ___ Asie
   ___ Australie
   ___ Antarctique

5. Plus haut niveau de scolarité complété : ___ École primaire
   ___ École secondaire
   ___ CÉGEP
   ___ Baccalauréat
   ___ Maîtrise ou doctorat

6. Statut économique (revenu parental, si vous habitez avec eux; revenu familial, si vous vivez en couple/famille; revenu individuel, si vous vivez seul ou en co-location):

___ Faible (moins de 20 000$)

___ Moyen (20 000 - 50 000$)

___ Élevé (50 000$ et plus)

7. État civil : ___ Célibataire

___ Marié(e)

___ Veuf(ve)

___ Séparé(e)/divorcé(e)

___ Conjoint(e) de fait

8. Veuillez indiquer : votre taille: ______ cms ou ____ pieds ____ pouces;

votre poids : ______ kg ou ______ lbs ; et

votre tour de taille : ______ cms (utilisez le mètre ruban fourni par le chercheur).

9. Nombre moyen de cigarette(s) que vous fumez par semaine : ______

10. Nombre moyen de tasse(s) de boissons caféinées (taille de restaurant) que vous buvez par semaine (p. ex., café, thé, boissons gazeuses, etc.) : ______

11. Nombre moyen de minute(s) d'activité sportive que vous faites par semaine : ______

12. Avez-vous été diagnostiqué d'hypertension ? (encerclez votre réponse)

Oui ou **Non**

13. Prenez-vous des médicaments contre l'hypertension ? (encerclez votre réponse)

Oui ou **Non**

14. Avez-vous été diagnostiqué de diabète ? (encerclez vos réponses)

Type 1	**Oui**	ou	**Non**
Type 2	**Oui**	ou	**Non**

15. Prenez-vous des médicaments contre le diabète ? (encerclez votre réponse)

Oui ou **Non**

16. Prenez-vous des médicaments contre l'anxiété ? (encerclez votre réponse)

Oui ou **Non**

À être complété par chercheur

Distance interpupillaire : __________ m (p. ex.: .06m)

Score au Randot Test : __________

Notes au dossier :

Questionnaire sur la propension à l'immersion

Laboratoire de Cyberpsychologie de l'UQO*
(2002)

Indiquer votre réponse en inscrivant un "X" dans la case appropriée de l'échelle en 7 points. Veuillez prendre en compte l'échelle en entier lorsque vous inscrivez vos réponses, surtout lorsque des niveaux intermédiaires sont en jeu. Par exemple, si votre réponse est "une fois ou deux", la deuxième case à partir de la gauche devrait être utilisée. Si votre réponse est "plusieurs fois mais pas extrêmement souvent", alors la sixième case (ou la deuxième à partir de la droite) devrait être utilisée.

1. Devenez-vous facilement et profondément absorbé(e) lorsque vous visionnez des films ou des téléromans?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

2. Vous arrive-t-il d'être tellement absorbé(e) dans une émission de télévision ou un livre que les gens autour de vous ont de la difficulté à vous en tirer?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

3. Jusqu'à quel point vous sentez-vous mentalement éveillé(e) ou vif(ve) d'esprit en ce moment même?

|________|________|________|________|________|________|________|
PAS ÉVEILLÉ(E) MODÉRÉMENT COMPLÈTEMENT ÉVEILLÉ(E)

4. Vous arrive-t-il d'être tellement absorbé(e) dans un film que vous n'êtes pas conscient(e) des choses qui se passent autour de vous?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

5. À quelle fréquence vous arrive-t-il de vous identifier intimement avec les personnages d'une histoire?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

6. Vous arrive-t-il d'être tellement absorbé(e) dans un jeu vidéo que vous avez l'impression d'être à l'intérieur du jeu plutôt qu'en train de manœuvrer des manettes de jeu et de regarder un écran?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

7. Comment vous sentez-vous sur le plan de la forme physique aujourd'hui?

|________|________|________|________|________|________|________|
PAS EN FORME MODÉRÉMENT BIEN EXTRÊMEMENT BIEN

8. Dans quelle mesure êtes-vous efficace pour vous couper des distractions extérieures lorsque vous êtes en train de faire quelque chose?

|________|________|________|________|________|________|________|
PAS TRÈS BON(NE) PLUTÔT BON(NE) TRÈS BON(NE)

9. Lorsque vous assistez à un match sportif, vous arrive-t-il de devenir tellement pris(e) par le match que vous réagissez comme si vous étiez un des joueurs?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

10. Vous arrive-t-il d'être tellement absorbé(e) dans des rêveries, en plein jour, que vous n'êtes pas conscient des choses qui se passent autour de vous?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

11. Vous arrive-t-il d'avoir des rêves qui semblent tellement réels que vous vous sentez désorienté(e) au réveil?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

12. Quand vous faites du sport, vous arrive-t-il d'être à ce point absorbé(e) que vous perdez la notion du temps?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

13. Dans quelle mesure arrivez-vous à vous concentrer lors d'activités plaisantes?

|________|________|________|________|________|________|________|
PAS DU TOUT MODÉRÉMENT BIEN TRÈS BIEN

14. À quelle fréquence jouez-vous à des jeux vidéos? (SOUVENT devrait correspondre à tous les jours, ou tous les deux jours, en moyenne)

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

15. Vous est-il déjà arrivé(e) d'être excité(e) lorsque vous visionnez une scène de poursuite ou de combat à la télévision ou dans un film?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

16. Vous est-il déjà arrivé(e) d'être apeuré(e) par quelque chose se produisant à la télévision ou dans un film?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

17. Vous est-il déjà arrivé(e) de demeurer apeuré(e) longtemps après le visionnement d'un film d'épouvante?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

18. Vous arrive-t-il de devenir absorbé(e) à un point tel dans une activité donnée que vous en perdez la notion du temps?

|________|________|________|________|________|________|________|
JAMAIS À L'OCCASION SOUVENT

* Inspiré de la version originale de : Witmer, B.G. & Singer. M.J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence : Teleoperators and Virtual Environments*, *7*(3), 225-240.

Dernière version : Mars 2013

L'Échelle d'Absorption de Tellegen Modifiée

(Traduction & adaptation de Jamieson, 2005)

Veuillez remplir ce questionnaire en encerclant le chiffre qui, en fonction de votre expérience, exprime le mieux la fréquence selon laquelle les énoncés suivants sont vrais pour vous. Il est nécessaire que vous répondiez le plus honnêtement possible :
« 0 » correspond à « jamais »;
« 1 » correspond à « au moins une fois »;
« 2 » correspond à « occasionnellement »;
« 3 » correspond à « souvent »; et
« 4 » correspond à « très souvent ».

1.	Je sens et vis les choses comme lorsque j'étais enfant.	0	1	2	3	4
2.	Je suis très ému(e) par un langage éloquent ou poétique.	0	1	2	3	4
3.	En regardant un film, une émission de TV, ou une pièce de théâtre, je deviens tellement impliqué(e) que je m'oublie moi-même et mon environnement, et je vis l'histoire comme si elle était réelle et comme si j'y participais.	0	1	2	3	4
4.	Si je regarde intensément une image puis que j'arrête de la regarder, je suis capable de la « voir » comme si j'étais encore en train de la regarder.	0	1	2	3	4
5.	Je me sens comme si mon esprit pouvait envelopper le monde entier.	0	1	2	3	4
6.	J'aime bien regarder les formes des nuages changer dans le ciel.	0	1	2	3	4
7.	J'imagine certaines choses (ou rêvasse) de façon tellement vivace qu'elles maintiennent mon attention, comme un bon film ou une histoire.	0	1	2	3	4
8.	Je crois que je sais vraiment ce que certaines personnes veulent dire lorsqu'elles parlent d'expériences mystiques.	0	1	2	3	4
9.	Je "sors" de mon moi habituel et vis un état d'être complètement différent.	0	1	2	3	4
10.	Des textures comme la laine, le sable et le bois me rappellent des couleurs.	0	1	2	3	4
11.	J'éprouve les choses comme si elles étaient doublement vraies/réelles.	0	1	2	3	4

12.	Quand j'écoute de la musique, je suis tellement pris(e) dedans que je ne me rends compte de rien d'autre.	0	1	2	3	4
13.	Si je veux, je peux imaginer que mon corps est tellement lourd, que je ne peux pas le bouger, même si je le voulais.	0	1	2	3	4
14.	Je peux parfois sentir la présence d'une autre personne, avant de vraiment la voir ou de l'entendre.	0	1	2	3	4
15.	Le crépitement et les flammes d'un feu de bois stimulent mon imagination.	0	1	2	3	4
16.	Je peux être complètement imprégné(e) par la nature ou l'art que je me sens comme si mon état de conscience entier était en quelque sorte altéré temporairement.	0	1	2	3	4
17.	Des couleurs différentes ont une signification distincte et spéciale pour moi.	0	1	2	3	4
18.	Je pars dans mes propres pensées lorsque je fais une tâche routinière et j'oublie ce que je suis en train de faire réellement, et quelques minutes après, je me rends compte que j'ai complété la tâche.	0	1	2	3	4
19.	Je me souviens de certaines expériences passées de ma vie avec tellement de clarté et de vivacité que j'ai l'impression de les revivre ou presque.	0	1	2	3	4
20.	Certaines choses peuvent ne pas faire de sens pour les autres, mais elles en font pour moi.	0	1	2	3	4
21.	En jouant une pièce de théâtre, je pense que je pourrais vraiment ressentir les émotions du personnage et fusionner avec lui sur le moment présent, en m'oubliant moi-même et l'audience.	0	1	2	3	4
22.	Mes pensées n'apparaissent pas sous forme de mots, mais comme des images visuelles.	0	1	2	3	4
23.	Je me réjouis de petites choses (comme l'étoile à cinq bras qui apparait lorsqu'on coupe une pomme le long du trognon ou les couleurs des bulles de savon).	0	1	2	3	4

24.	En écoutant de la musique d'orgue ou une autre musique puissante, je me sens comme si je m'élevais dans les airs.	0	1	2	3	4
25.	Selon comment je l'écoute, je peux changer du bruit en musique.	0	1	2	3	4
26.	Certains de mes souvenirs les plus vifs sont rappelés par des parfums et des odeurs.	0	1	2	3	4
27.	Certains morceaux de musique me rappellent des images ou des motifs de couleur qui bougent.	0	1	2	3	4
28.	Je sais ce que quelqu'un va dire avant qu'il/elle ne le dise.	0	1	2	3	4
29.	J'ai des « souvenirs physiques », par exemple après avoir nagé je peux avoir l'impression d'être encore dans l'eau.	0	1	2	3	4
30.	Le son d'une voix peut être tellement fascinant pour moi que je peux juste continuer à l'écouter.	0	1	2	3	4
31.	Je sens en quelque sorte la présence de quelqu'un qui n'est pas là physiquement.	0	1	2	3	4
32.	Les pensées et les images me viennent sans aucun effort.	0	1	2	3	4
33.	Je trouve que différentes odeurs ont des couleurs différentes.	0	1	2	3	4
34.	Je suis profondément ému(e) par un coucher de soleil.	0	1	2	3	4

Questionnaire sur les cybermalaises

Laboratoire de Cyberpsychologie de l'UQO (Traduit de Kennedy, R.S.et al., 1993)

Consignes : Encerclez à quel point chaque symptôme ci-dessous vous affecte présentement.

1. Inconfort général	Pas du tout	Un peu	Modérément	Sévèrement
2. Fatigue	Pas du tout	Un peu	Modérément	Sévèrement
3. Mal de tête	Pas du tout	Un peu	Modérément	Sévèrement
4. Fatigue des yeux	Pas du tout	Un peu	Modérément	Sévèrement
5. Difficulté à faire le focus	Pas du tout	Un peu	Modérément	Sévèrement
6. Augmentation de la salivation	Pas du tout	Un peu	Modérément	Sévèrement
7. Transpiration	Pas du tout	Un peu	Modérément	Sévèrement
8. Nausées	Pas du tout	Un peu	Modérément	Sévèrement
9. Difficulté à se concentrer	Pas du tout	Un peu	Modérément	Sévèrement
10. Impression de lourdeur dans la tête	Pas du tout	Un peu	Modérément	Sévèrement
11. Vision embrouillée	Pas du tout	Un peu	Modérément	Sévèrement
12. Étourdissement les yeux ouverts	Pas du tout	Un peu	Modérément	Sévèrement
13. Étourdissement les yeux fermés	Pas du tout	Un peu	Modérément	Sévèrement
14. *Vertiges	Pas du tout	Un peu	Modérément	Sévèrement
15. **Conscience de l'estomac	Pas du tout	Un peu	Modérément	Sévèrement
16. Rots	Pas du tout	Un peu	Modérément	Sévèrement

* Les vertiges sont vécus comme une perte de l'orientation par rapport à la position verticale.

** L'expression « conscience de l'estomac » est habituellement utilisée pour désigner un sentiment d'inconfort sans nausée.

Dernière version : octobre 2002

Annexe F : Instructions préimmersion

Instruction préimmersion

Ce document a pour but de vous fournir les informations nécessaires pour une participation fructueuse à ce projet de recherche.

APERÇU

Durant cette expérience, vous allez visiter certaines pièces d'un appartement virtuel. Chacune de ces pièces est représentée selon des détails visuels quelque peu différents et, par le biais de deux phénomènes nommés le « **sentiment de présence** » et le « **sentiment de réalité** », nous allons vous demander de donner une appréciation de votre expérience dans chacune de ces pièces.

BUT DE L'ÉTUDE

Le but du projet est d'examiner le lien entre le niveau de détail des images et les sentiments de **présence** et de **réalité**.

LE SENTIMENT DE PRÉSENCE

Lorsque vous serez immergé dans l'environnement virtuel, vous aurez peut-être l'impression de vraiment être dans cet appartement, alors que vous êtes encore dans le laboratoire.

Le sentiment de présence fait référence à ce **sentiment d'être là, dans la pièce de l'appartement**.

LE SENTIMENT DE RÉALITÉ

Dans chacune des pièces, nous allons également vous demander de coter votre sentiment de réalité.

Le sentiment de réalité fait référence au **sentiment que votre expérience dans l'environnement virtuel est réelle**.

Il est important de ne pas confondre le phénomène de réalité avec le réalisme. Ici, on ne parle pas du réalisme des objets virtuels, mais de votre expérience dans l'environnement: **à quel point est-ce que ce que vous vivez semble réel.**

DÉROULEMENT DE L'EXPÉRIMENTATION

Lorsque vous aurez fini de lire ce document, un des chercheurs vous accompagnera à la pièce pour l'expérimentation. Là, on vous aidera à placer des capteurs physiologiques qui nous permettrons d'enregistrer votre rythme cardiaque et la conductance électrique de votre peau. Une fois la fonctionnalité de cet équipement vérifiée, on vous aidera à mettre le visio-casque, on vous remettra une souris sans fil, et on vous positionnera à une place précise pour débuter l'expérimentation. À ce moment de l'immersion, vous vous trouverez dans le hall d'entrée de l'appartement.

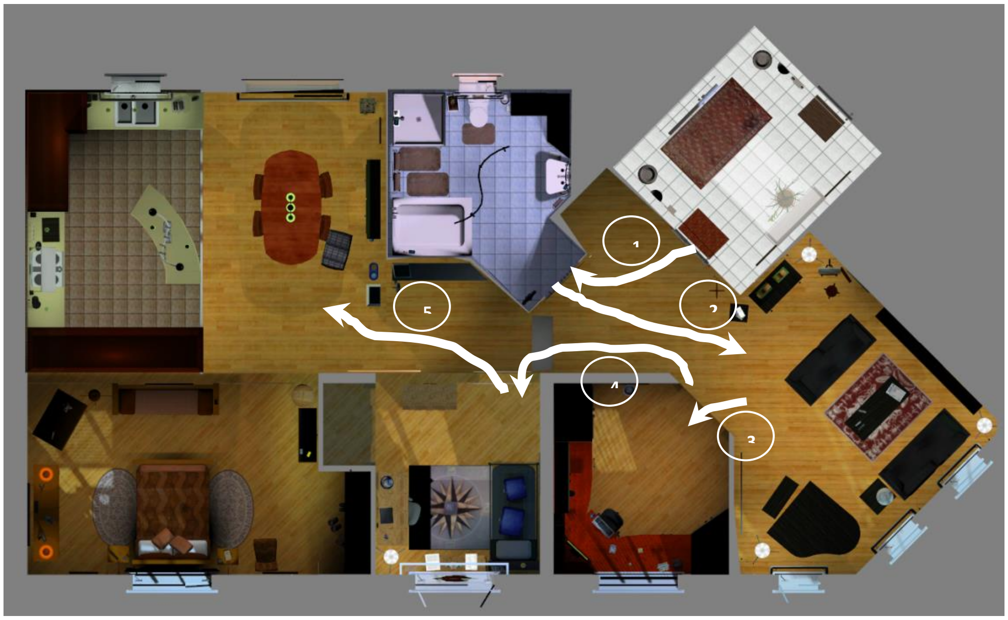
Là, on vous laissera quelques minutes pour vous habituer à la sensation d'être, et de vous déplacer, dans l'environnement virtuel. Pour les petits mouvements il vous suffit de bouger de façon ordinaire (vous tourner, vous baisser, etc.). Par contre, pour vous déplacer, vous devez utiliser la souris sans-fil: pour avancer, appuyez sur le bouton de gauche, et pour reculer, appuyez sur le bouton de droite. Pour ouvrir les portes, il vous suffit de vous placer devant celle-ci, et d'actionner (en appuyant dessus) la petite roue de la souris sans-fil. Veuillez noter que les portes des placards ne peuvent pas être ouvertes.

Une fois que vous vous sentirez à l'aise avec l'équipement et que vous êtes prêt à commencer, avisez-en le chercheur. Il enregistrera alors quelques mesures physiologiques, puis une bande sonore vous demandera de coter, de 0% à 100%, vos sentiments de présence (« Sur une échelle de 0% à 100%, à quel point vous sentez vous présent ici dans l'entrée. ») et de réalité (« Sur une échelle de 0% à 100%, à quel point est-ce que votre expérience ici dans …. vous semble-t-elle réelle »). Ensuite, une bande sonore vous rappellera le scénario, et finalement on vous invitera à entrer dans l'appartement et à vous diriger vers, et entrer dans, la salle de bain. Au moment que vous franchirez le pas de la porte donnant sur le reste de l'appartement, une bande sonore de musique de fond débutera.

SCÉNARIO DE L'IMMERSION

Votre mission est de trouver un couteau utilisé pour un crime de sang. En effet, un meurtre a été commis dans le quartier (le meurtrier court encore), et vous faites partie d'une équipe d'officiers de sécurité chargés de le trouver. Vous êtes personnellement responsable de vérifier dans cinq pièces de cet appartement, **dans cet ordre précis**: la salle de bain, le salon, le bureau, la chambre à coucher et la cuisine/salle à manger; des instructions pré-enregistrées vous donneront les directions pour vous rendre à chacune des pièces (p.ex., « Pour aller au salon, tournez à gauche en sortant de la salle de bain. »).

Trajet à suivre dans l'appartement



On vous demande de vérifier chaque pièce pendant une minute; prenez votre temps, ce n'est pas une course et ce n'est pas grave si vous ne trouvez pas le couteau. Après cette minute, une instruction pré-enregistrée vous demandera: « Sur une échelle de 0% à 100%, à quel point vous sentez vous présent ici dans …? » et quelques secondes après la fin de ces instructions, une autre instruction pré-enregistrée demandera : « Sur une échelle de 0% à 100%, à quel point est-ce que votre expérience ici dans …. vous semble-t-elle réelle? »; **l'ordre de ces questions variera, assurez-vous donc de bien les écouter**. Si vous avez fini de vérifier la pièce avant l'instruction verbale (ceci est possible pour les petites pièces), alors recommencer un autre tour de la pièce; il ne faut surtout **pas quitter la pièce** avant qu'on vous ait demandé, et que vous ayez donné, vos score de présence et de réalité. Si vous n'avez pas fini de faire le tour de la pièce (ceci est probable pour les grandes pièces), ce n'est pas grave; arrêtez votre recherche et cotez vos sentiments de présence et de réalité lorsqu'on vous le demande.

N'essayez pas de comparer consciemment les détails visuels des différentes pièces, concentrez-vous simplement à chercher l'arme.

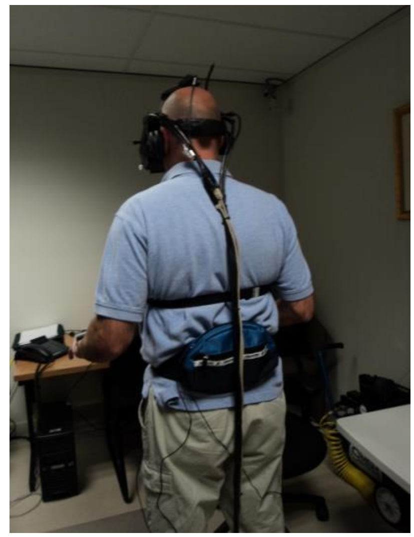
Lorsque vous aurez fini de coter vos sentiments de présence et de réalité, une instruction pré-enregistrée vous indiquera les directions pour vous rendre à la prochaine pièce, où vous répéterez la procédure.

Lorsque vous aurez coté vos sentiments de présence et de réalité dans la cuisine/salle à manger (la dernière pièce), le chercheur vous aidera à enlever le visio-casque et vous demandera de répondre à une série de questionnaires.

Pour finir, vous aurez l'opportunité de poser des questions (sur la réalité virtuelle, le protocole de recherche, etc.).

NOTES

Durant votre visite de l'appartement, dans le but de ne pas influer sur votre expérience dans l'environnement virtuel, **le chercheur tentera de minimiser la communication avec vous**. Cela veut dire que, s'il estime que cela pourrait nuire à l'expérimentation, il ne répondra peut-être pas à vos commentaires ou questions; si cela arrive, continuez simplement le scénario et garder les questions pour après les questionnaires. Bien sûr, si c'est une question de sécurité, le chercheur prendra les mesures nécessaires.



En parlant de sécurité… le visio-casque est relié à l'ordinateur par un câble qui va « trainer » derrière vous. Il est possible que, selon vos mouvements et rotations, ce câble s'enroule un peu autour de vos pieds. Si c'est le cas, essayez de vous en dégager en prenant un pas au dessus. Si cela devient trop difficile, le chercheur vous aidera. De plus, si durant votre immersion vous vous approchez trop d'un obstacle réel dans le laboratoire (un mur ou le bureau), le chercheur vous en avisera, et vous donnera les instructions appropriées avant de vous laisser continuer votre exploration de l'appartement virtuel. Dans tous les cas, il s'assurera de votre sécurité.

Que ce soit pour les questionnaires ou les cotes verbales, il n'y a **pas de bonnes ou de mauvaises réponses**. Ce qui nous intéresse, ce sont **VOS réponses**, à vous.

LE CYBERMALAISE

Le cybermalaise s'apparente aux malaises du mal des transports (« motion sickness ») et il peut se manifester pendant, ou suite à une immersion virtuelle. On croit qu'il provient surtout d'un conflit entre trois systèmes sensoriels: le visuel, le vestibulaire et le proprioceptif. En effet, lorsque vous vous déplacez à l'aide de la souris sans fil, vos yeux vont détecter un mouvement alors que les deux autres systèmes ne le détectent pas; c'est ce conflit qui peut mener au cybermalaise. De plus, quand vous faites de petits mouvements avec votre tête, il y a un très léger délai entre ce mouvement et la représentation de ce mouvement sur l'écran. Aussi petit qu'il soit, ce décalage peut, suite à de multiples répétitions, mener à un cybermalaise.

Les symptômes potentiels sont similaires à ceux causés par la lecture dans une automobile en mouvement: la fatigue des yeux, la vision embrouillée, un mal de tête, le vertige, le déséquilibre, un étourdissement, et dans des cas extrêmes, le vomissement. D'autres symptômes potentiels pendant ou suite à une immersion virtuelle incluent: de l'inconfort général, la difficulté à faire le focus, l'augmentation de la salivation, la transpiration, l'impression de lourdeur dans la tête, conscience de l'estomac et les rots.

La proportion d'individus qui ressentent des effets secondaires sévères et à long terme est semblable à la proportion d'individus étant plus sensibles aux malaises dus au déplacement.

Les cybermalaises ne représentent pas une maladie, mais plutôt une réponse physiologique normale à la présence d'un stimulus inhabituel. Leur intensité varie beaucoup d'une personne à une autre.

Afin de réduire les risques de sentir un cybermalaise, **éviter de bouger trop rapidement**. En particulier, **éviter les mouvements brusques de la tête**.

Si vous êtes victime d'un cybermalaise et qu'il est tel que vous ne vous sentez pas capable de continuer l'immersion, avisez-en le chercheur; il arrêtera l'expérimentation, il vous aidera à enlever l'équipement et à vous assoir.

LES SENTIMENTS DE PRÉSENCE ET DE RÉALITÉ …UNE DERNIÈRE FOIS

Le sentiment de présence fait référence à l'impression d'être là, dans un lieu précis. Dans le cas de cette expérimentation, on vous demandera **à quel point vous vous sentez vraiment là**, sur une échelle de 0% à 100%, dans chacune des cinq pièces de l'appartement.

Le sentiment de réalité fait référence au sentiment que votre expérience dans l'environnement virtuel semble réelle, à quel point ce que vous vivez semble réel. Dans le cas de cette expérimentation, on vous demandera **à quel point est-ce que votre expérience dans chacune des cinq pièces vous semble réelle**, sur une échelle de 0% à 100%.

Prenez garde de répondre à la bonne question, car l'ordre dans lequel elles seront posées variera d'une pièce à l'autre.

Annexe G : Questionnaires post-immersion

ITC-SOPI

SVP lire les instructions avant de répondre aux questions

Instructions :

Nous sommes intéressés à connaître vos impressions par rapport à l'expérience que vous venez de vivre dans l'environnement virtuel. Certaines questions concernent le « CONTENU » de l'environnement virtuel. Par exemple l'histoire, les scènes ou les événements, ou tout ce que vous pouvez voir, entendre ou ressentir à l'intérieur de l'environnement virtuel. L'environnement virtuel et son contenu (incluant les représentations de personnes, animaux ou personnes animées, lesquels nous appelons « PERSONNAGE ») sont différents du « MONDE RÉEL »: le monde dans lequel vous vivez quotidiennement. SVP vous référez à cette page si vous êtes incertain(e) de la signification de n'importe quelle des questions.

Ce questionnaire comprend deux parties:

La PARTIE A interroge à propos de vos pensées et sentiments après que l'expérience dans l'environnement virtuel soit terminée.

La PARTIE B concerne vos pensées et sentiments pendant votre recherche du couteau dans la cuisine/salle à manger.

SVP ne passez pas trop de temps sur n'importe quelle des questions. Votre première réponse est habituellement la meilleure. Pour chaque question, choisissez la réponse qui se RAPPROCHE le plus de la vôtre.

SVP rappelez-vous qu'il n'y a pas de bonnes ou mauvaises réponses - nous sommes simplement intéressés à connaître VOS pensées et sentiments à propos de l'environnement virtuel.

SVP ne discutez pas de ce questionnaire avec qui que ce soit qui pourraient le compléter puisque cela pourrait affecter vos réponses ou leurs réponses.

Toutes vos réponses seront traitées confidentiellement.

PARTIE A

SVP indiquez JUSQU'À QUEL POINT VOUS ÊTRE EN ACCORD OU EN DÉSACCORD avec chacun des énoncés suivants en encerclant seulement UN nombre, sur l'échelle de 5 points ci-dessous.

(Fortement en désaccord)	(En désaccord)	(Ni en accord ou en désaccord)	(En accord)	(Fortement en accord)
1	**2**	**3**	**4**	**5**

<u>APRÈS</u> MON EXPÉRIENCE DANS L'ENVIRONNEMENT VIRTUEL ...

1. Je me suis senti(e) triste que mon expérience était terminée 1 2 3 4 5

2. Je me suis senti(e) désorienté(e) 1 2 3 4 5

3. J'ai eu l'impression que je revenais d'un voyage 1 2 3 4 5

4. J'aurais aimé que l'expérience se poursuive 1 2 3 4 5

5. Je me souviens clairement de certaines parties de l'expérience 1 2 3 4 5

6. Je recommanderais l'expérience à mes amis 1 2 3 4 5

PARTIE B

SVP indiquez JUSQU'À QUEL POINT VOUS ÊTRE EN ACCORD OU EN DÉSACCORD avec chacun des énoncés suivants en encerclant seulement UN nombre, sur l'échelle de 5 points ci-dessous.

(Fortement en désaccord)	(En désaccord)	(Ni en accord ou en désaccord)	(En accord)	(Fortement en accord)
1	**2**	**3**	**4**	**5**

<u>DURANT</u> MON EXPÉRIENCE DANS LA CUISINE/SALLE À MANGER ...

1. Je me suis senti(e) « absorbé(e) »	1	2	3	4	5
2. Je me suis senti(e) impliqué(e) (dans la cuisine/salle à manger)	1	2	3	4	5
3. J'ai perdu la notion du temps	1	2	3	4	5
4. J'ai eu l'impression de pouvoir interagir avec la cuisine/salle à manger.........	1	2	3	4	5
5. La cuisine/salle à manger me semblait naturelle	1	2	3	4	5
6. Je me suis senti(e) comme si j'étais « là »	1	2	3	4	5
7. J'ai eu l'impression que les personnages et/ou objets pouvaient presque me toucher(e)	1	2	3	4	5
8. Je me suis amusé(e)	1	2	3	4	5
9. J'ai eu l'impression de visiter la cuisine/salle à manger.	1	2	3	4	5
10. Je me suis senti(e) fatigué(e)	1	2	3	4	5

(Fortement en désaccord)	(En désaccord)	(Ni en accord ou en désaccord)	(En accord)	(Fortement en accord)
1	**2**	**3**	**4**	**5**

<u>DURANT</u> MON EXPÉRIENCE DANS LA CUISINE/SALLE À MANGER ...

11. Le contenu me semblait réaliste 1 2 3 4 5

12. J'ai senti que je n'étais pas *juste* en train de regarder quelque chose.......... 1 2 3 4 5

13. J'ai eu l'impression de bouger en réponse à certaines parties de de la cuisine/salle à manger.............. .... 1 2 3 4 5

14. Je me suis senti(e) étourdi(e) 1 2 3 4 5

15. J'ai eu l'impression que la cuisine/salle à manger faisait partie du monde réel 1 2 3 4 5

16. Mon expérience était intense 1 2 3 4 5

17. J'ai porté plus d'attention sur la cuisine/salle à manger qu'à mes propres pensées (préoccupations personnelles, rêveries, etc.) 1 2 3 4 5

18. J'ai eu l'impression d'être présent(e) dans la cuisine/salle à manger 1 2 3 4 5

19. J'ai eu l'impression de pouvoir bouger des objets (dans la cuisine/salle à manger)…………………………………………………………………...1 2 3 4 5

20. La cuisine/salle à manger visitée pourrait réellement exister dans le monde réel……………………………….......... .... 1 2 3 4 5

21. J'ai ressenti une fatigue des yeux 1 2 3 4 5

(Fortement en désaccord)	(En désaccord)	(Ni en accord ou en désaccord)	(En accord)	(Fortement en accord)
1	**2**	**3**	**4**	**5**

<u>DURANT</u> MON EXPÉRIENCE DANS LA CUISINE/SALLE À MANGER ...

22. Je pouvais presque sentir différentes caractéristiques de la cuisine/salle à manger ……………... 1 2 3 4 5

23. J'ai eu l'impression que les personnages étaient conscients de ma présence. S/O

24. J'ai ressenti les sons provenant de différentes directions à l'intérieur de la cuisine/salle à manger 1 2 3 4 5

25. Je me suis senti(e) enveloppé(e) par la cuisine/salle à manger 1 2 3 4 5

26. J'ai ressenti des nausées 1 2 3 4 5

27. J'ai vraiment senti que les objets étaient solides.. 1 2 3 4 5

28. J'ai eu l'impression que je pouvais atteindre ou toucher les objets 1 2 3 4 5

29. J'ai senti que la température changeait en fonction de mon positionnement dans la cuisine/salle à manger 1 2 3 4 5

30. J'ai répondu émotionnellement 1 2 3 4 5

31. J'ai senti que *tous* mes sens étaient tous stimulés en même temps 1 2 3 4 5

32. Le contenu me plaisait 1 2 3 4 5

33. Je me sentais capable de changer le cours des événements dans La cuisine/salle à manger 1 2 3 4 5

(Fortement en désaccord)	(En désaccord)	(Ni en accord ou en désaccord)	(En accord)	(Fortement en accord)
1	**2**	**3**	**4**	**5**

<u>DURANT</u> MON EXPÉRIENCE DANS LA CUISINE/SALLE À MANGER ...

34. J'avais l'impression d'être dans le même espace que les objets 1 2 3 4 5

35. J'ai eu l'impression que certaines parties de la cuisine/salle à manger (p. ex. objets) répondaient à mes actions.. 1 2 3 4 5

36. J'ai trouvé réaliste de pouvoir bouger les objets dans l'environnement virtuel .... S/O

37. J'ai senti que j'avais un mal de tête.. 1 2 3 4 5

38. J'ai eu l'impression que je participais dans la cuisine/salle à manger 1 2 3 4 5

<u>S'il y a quoique ce soit que vous aimeriez ajouter, SVP utilisez l'espace ci-dessous</u> :

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<u>SVP VÉRIFIEZ SI VOUS AVEZ RÉPONDU À TOUTES LES QUESTIONS</u>

Questionnaire de contre vérification de la manipulation

1. Pendant votre recherche du couteau **dans la cuisine/salle à manger**, avez-vous perçu une odeur particulière? (encerclez votre réponse)

   Oui ou **Non**

Si vous avez répondu « **Non** » à la question précédente, vous avez fini ce questionnaire.
Si vous avez répondu « **Oui** » à la question précédente, veuillez continuer ce questionnaire.

2. Veuillez SVP décrire cette odeur? « Cela sentait comme… »

   ____

3. Selon vous, quelle était la source de cette odeur dans la cuisine/salle à manger?

   ____

4. Quel est le niveau de concordance entre cette odeur et la cuisine/salle à manger? En d'autres mots, à quel point cette odeur va-t-elle avec la cuisine que vous avez vue? (inscrivez un X dans une des sept cases)

|____________|____________|____________|____________|____________|____________|

Extrêmement Non-concordante		**Plutôt non-concordante**	**Plutôt concordante**		**Extrêmement concordante**

5. Trouviez-vous cette odeur agréable ou désagréable? (inscrivez un X dans une des six cases)

|_________|_________|_________|_________|_________|_________|

Extrêmement désagréable		**Plutôt désagréable**	**Plutôt agréable**		**Extrêmement agréable**

6. Quel était le niveau d'intensité de cette odeur? (inscrivez un X dans une des sept cases)

|________|________|________|________|________|________|________|

Très faible intensité **Moyenne** **Très forte intensité**

7. À quel point est-ce que cette odeur vous semblait familière? (inscrivez un X dans une des sept cases)

|________|________|________|________|________|________|________|

Pas du tout familière **Moyennement familière** **Très familière**

8. Est-ce que cette odeur vous rappelle, ou vous fait penser à un lieu, une chose, un évènement, ou quelqu'un? (encerclez votre réponse)

Oui ou **Non**

Si, oui, veuillez SVP le préciser:

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Questionnaire sur les cybermalaises

Laboratoire de Cyberpsychologie de l'UQO (Traduit de Kennedy, R.S.et al., 1993)

Consignes : Encerclez à quel point chaque symptôme ci-dessous vous affecte présentement.

1. Inconfort général	Pas du tout	Un peu	Modérément	Sévèrement
2. Fatigue	Pas du tout	Un peu	Modérément	Sévèrement
3. Mal de tête	Pas du tout	Un peu	Modérément	Sévèrement
4. Fatigue des yeux	Pas du tout	Un peu	Modérément	Sévèrement
5. Difficulté à faire le focus	Pas du tout	Un peu	Modérément	Sévèrement
6. Augmentation de la salivation	Pas du tout	Un peu	Modérément	Sévèrement
7. Transpiration	Pas du tout	Un peu	Modérément	Sévèrement
8. Nausées	Pas du tout	Un peu	Modérément	Sévèrement
9. Difficulté à se concentrer	Pas du tout	Un peu	Modérément	Sévèrement
10. Impression de lourdeur dans la tête	Pas du tout	Un peu	Modérément	Sévèrement
11. Vision embrouillée	Pas du tout	Un peu	Modérément	Sévèrement
12. Étourdissement les yeux ouverts	Pas du tout	Un peu	Modérément	Sévèrement
13. Étourdissement les yeux fermés	Pas du tout	Un peu	Modérément	Sévèrement
14. *Vertiges	Pas du tout	Un peu	Modérément	Sévèrement
15. **Conscience de l'estomac	Pas du tout	Un peu	Modérément	Sévèrement
16. Rots	Pas du tout	Un peu	Modérément	Sévèrement

* Les vertiges sont vécus comme une perte de l'orientation par rapport à la position verticale.

** L'expression « conscience de l'estomac » est habituellement utilisée pour désigner un sentiment d'inconfort sans nausée.

Dernière version : octobre 2002

Questionnaire de vérification des dimensions des odeurs

1. Veuillez SVP décrire l'odeur? « Cela sent comme… »

____

2. Trouvez-vous cette odeur agréable ou désagréable?
(Inscrivez un X dans une des six cases)

|_________|_________|_________|_________|_________|_________|

Extrêmement désagréable		Plutôt désagréable	Plutôt agréable		Extrêmement agréable

3. Quel est le niveau de concordance entre cette odeur et la cuisine/salle à manger? En d'autres mots, à quel point cette odeur va-t-elle avec la cuisine que vous avez vue?
(Inscrivez un X dans une des sept cases)

|____________|____________|____________|____________|____________|____________|

Extrêmement Non-concordante		Plutôt non-concordante	Plutôt concordante		Extrêmement concordante

4. Quel est l'intensité de cette odeur?
(Inscrivez un X dans une des sept cases)

|________|________|________|________|________|________|________|

Très faible intensité			Moyenne			Très forte intensité

5. À quel point est-ce que cette odeur vous semble-t-elle familière?
(Inscrivez un X dans une des sept cases)

|________|________|________|________|________|________|________|

Pas du tout familière			**Moyennement familière**			**Très familière**

6. Est-ce que cette odeur vous rappelle, ou vous fait penser à un lieu, une chose, un évènement, ou quelqu'un? (Encerclez votre réponse)

Oui ou **Non**

Si, oui, veuillez SVP le préciser:

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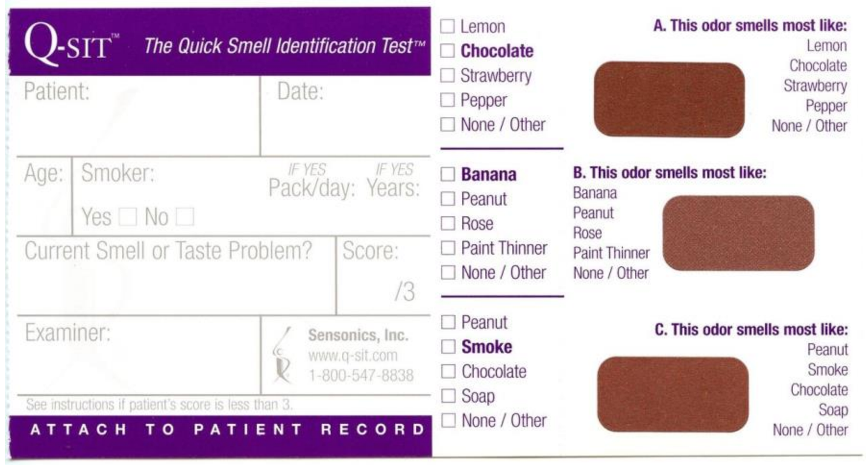
Test d'olfaction



Q-SIT™ The Quick Smell Identification Test™

Patient:

Date:

Age:

Smoker:

Yes ☐ No ☐

IF YES Pack/day:

IF YES Years:

Current Smell or Taste Problem?

Score:

/3

Examiner:

Sensonics, Inc.
www.q-sit.com
1-800-547-8838

See instructions if patient's score is less than 3.

ATTACH TO PATIENT RECORD

☐ Lemon
☐ **Chocolate**
☐ Strawberry
☐ Pepper
☐ None / Other

A. This odor smells most like:
Lemon
Chocolate
Strawberry
Pepper
None / Other

☐ **Banana**
☐ Peanut
☐ Rose
☐ Paint Thinner
☐ None / Other

B. This odor smells most like:
Banana
Peanut
Rose
Paint Thinner
None / Other

☐ Peanut
☐ **Smoke**
☐ Chocolate
☐ Soap
☐ None / Other

C. This odor smells most like:
Peanut
Smoke
Chocolate
Soap
None / Other