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RÉPONSES PHYSIOLOGIQUES CHEZ L'HUMAIN EN SITUATION DE CONTRAINTES AUGMENTÉES

THÈSE

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Dédicace

''Il faut continuer à mettre un pied devant l'autre

parce que ça aussi, ça passera....''

Alexandre Byette, Chef d'expédition

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LISTE DES ABREVIATIONS, SIGLES ET ACRONYMES

ATS: American Thoracic Society

ACSM: American College of Sport of Medicine

ANOVA: Analyse of variance

ASMT: Aerobic submaximal test

BF: Body Fat

COPD: Chronic Obstructive Pulmonary Disease

CSEP: Canadian Society for Exercise Physiology

CV: Capacité vitale

DXA: Dual-energy X-ray absorptiometry

EE: Energy Expenditure

FEV1: Forces Expiratory Volume in 1 sec

FC: Fréquence cardiaque

Fig.: Figure

GOLD: Global Initiative for Chronic Obstructive Lung Disease

HR: Heart Rate

HRR: Heart Rate Reserve

IMC: Indice de masse corporelle

JDK: JustDance on Kinect

JDPS: JustDance on PlayStation

JDPSs: JustDance on PlayStation in sitting position

MARS: Maximal aerobic running speed test

MCK: MiCoach on Kinect

MCPS: MiCoach on PlayStation

MET: Metabolic Equivalent of Task

MPOC: Maladie Pulmonaire Obstructive Chronique

MR : Maximal repetition

OMNI : Omnibus defined in the context of a perceived exertion metric refers to pictures

NMHPS : No More Heroes on PlayStation

NMHPSs : No More Heroes on PlayStation in sitting position

PANAS : Positive and Negative Affect Schedule

SPSS : Statistical Package for Social Science

PS : PlayStation

RM: Répétition maximal

SMAT : Specific maximal aerobic test

SRT :Simple reaction time

SWK : StarWars on Kinect

UQAM : Université du Québec à Montréal

VC :Vital capacity

VE: Ventilation

VEMS: Volume expiratoire maximal seconde

Vt: Volume courant

VT :Ventilation treashold

VO_2: Volume de consommation d'oxygène

VO_{2max}: Volume de consommation d'oxygène maximal

vs : Versus

XP : Expédition

LISTE DES SYMBOLES ET DES UNITES

bpm: Battements par minute

Clo : Unité de mesure de protection par les vêtements

g/cm^2 : Gramme par centimètre au carré

h : Heure

Kcal : Kilocalories

Kcal/h : Kilocalorie par heure

Km : Kilomètre

Km/h : Kilomètre par heure

Kg: Kilogramme

Kg/m^2 : Kilomètre par mètre au carré

L: Litre

Lb: Livre

m : Mètre

MJ :Megajoule

Ms : Milliseconde

m/s : Mètre par seconde

min: Minute

ml: Millilitre

pg/mg : Picogramme par milligramme

sec: Seconde

° : Degré

° C : Degré Celsius

%: Pourcentage

Δ: Delta

±: Plus ou moins

d : Cohen's effect size (effet de taille)

X^2 : Friedman test

p : valeur-p

RÉSUMÉ

Les contraintes augmentées dues à l'environnement ou une maladie peuvent avoir des conséquences importantes sur les capacités physiologiques et sur le maintien les capacités fonctionnelles chez l'être humain. **Objectif:** L'objectif de la présente thèse est d'observer les réponses physiologiques dans deux situations de contraintes augmentées; soit lors d'une expédition en milieu polaire avec un groupe de jeunes adultes et lors d'activité physique où la réadaptation proposée utilise un jeu vidéo actif chez des personnes atteintes de maladies pulmonaires obstructives chroniques (MPOC). L'objectif secondaire de la thèse est de proposer des solutions utilisant les technologies actuelles pour aider à atténuer ces contraintes, par exemple, à l'aide de la télémédecine. **Méthodologie:** 6 explorateurs (3 hommes et 3 femmes) ont effectué une expédition d'un mois en complète autonomie en Antarctique. Des tests pré et post expédition ont été effectués: un test de composition corporelle (DXA), un test aérobie progressif à l'aide d'un analyseur métabolique portable (K4b2, Cosmed, It), un test de force maximal (presse assise, tirage à la barre haute et de développé assis) et des tests d'endurance musculaire (suspension à la barre haute et la chaise au mur). Certaines mesures ont été prises durant l'expédition permettant de suivre les réponses physiologiques, telles que la température orale, le temps de réaction simple ainsi que les fréquences cardiaques à l'aide d'une chemise intelligente (Astroskin, Agence Spatial Canadienne, CA). De plus, 10 joueurs expérimentés, 22 employés d'Ubisoft (11 femmes et 11 hommes) et 22 patients MPOC modérés à sévères (11 femmes et 11 hommes) ont été recruté pour jouer à des jeux vidéo actifs. Les jeux vidéo actifs ont été réalisés à l'aide d'un analyseur métabolique portable (K4b2, cosmed, It) afin d'observer les réponses physiologiques tel que les fréquences cardiaques, la consommation d'oxygène (VO_2) et la dépense énergétique durant les jeux suivants: Just Dance avec Kinect (XBOX 360, Microsoft,USA), Just Dance avec PSmove (PlayStation, Sony, Japan), MiCoach avec Kinect, MiCoach avec PSmove, StarWars Kinect et No More Heros avec PSmove ainsi que le jeu Shape-Up où les mini-jeux suivants ont été sélectionnés: Stunt Run (marche), Squat me to the Moon (squats), To the core (rotation du tronc) et Arctic Punch (boxe). En raison de la taille de certains échantillons, un test Sahpiro-Wilk a été effectué afin de vérifier la distribution des données. Un test T apparié a été utilisé pour des données distribuées normalement et le test de Wilcoxon pour les autres valeurs afin de comparer avant et après expédition. **Résultats:** Les exploratrices ont augmenté significativement leur masse maigre (45,4 ± 4.4 kg vs 47.1 ± 4.1 kg pré vs post-expédition respectivement, $t(4)= -3.129$, $p= 0,035$, $d= -0,12$), la VO_2 de pointe à des tests aérobies spécifiques était significativement augmentée (40,8 ± 4,7 vs 47,0 ± 7,3 ml/kg/min pré vs post expédition respectivement, $z= 2,207$, $p= 0,027$) et les tests musculaires se sont maintenus où aucune différence significative n'a pu être observée à l'exception de la jambe gauche où la force maximale extrapolée (1RMextrapolée) était significativement supérieure (295 ± 110 lb vs 364 ± 135 lb pré vs post expédition respectivement, t(5)= -3,252, p= 0,031, d= -056). Les mesures prises durant l'expédition n'ont pas évolué significativement durant l'expédition. Toutefois, il est à noter que les fréquences cardiaques durant la première semaine indiquaient un profil d'intensité élevé, représentant plus de 50% de la fréquence cardiaque de réserve pendant plusieurs heures. Pour ce qui est des joueurs inactifs, certains jeux actifs ont permis d'observer une moyenne d'intensité d'activité physique à vigoureux (au-dessus de 6 METS selon l'ACSM): le jeu JustDance avec la Kinect (6,87 ± 1,26 METs) et le mini-jeu Squat me to the moon du Jeu Shape Up (7 ± 1 METs). De plus, des patients MPOC ont performé ce jeu avec quelques modifications afin d'atteindre une intensité de 4,4 ± 1,1 METs, une intensité modérée qui correspond aux recommandations de l'American Thoracic Society (ATS). **Conclusion:** Les réponses physiologiques aux contraintes augmentées qui ont été présentées semblent avoir le potentiel d'aider les personnes en situation de contraintes par les technologies utilisées. Ces technologies permettraient une piste de solution pour de futures expéditions et pour les patients MPOC. La télémédecine et les technologies actuelles pourraient favoriser des solutions accessibles et efficaces afin de diminuer les contraintes rencontrées autant dans le milieu de l'expédition, mais également dans le milieu de la santé et possiblement pour d'autres populations comme des travailleurs en milieux extrêmes et en promotion de l'activité physique.

Mots-Clefs: Expédition en Antarctique, MPOC, télémédecine, jeux vidéo actifs

INTRODUCTION

Le corps humain possède des mécanismes permettant de garder son homéostasie et ainsi permettre la survie de celui-ci. Lors d'une contrainte augmentée, que ce soit par l'environnement ou dû à une maladie, le corps doit réagir pour tenter de garder cet état d'équilibre. Les réponses physiologiques lors de contraintes augmentées présentées dans le cadre de la présente thèse, soit lors d'une expédition en milieu polaire et lors d'une atteinte de maladie pulmonaire obstructive chronique (MPOC) physiquement active où la réadaptation proposée utilise un jeu vidéo actif, peuvent être variées et dépendent de plusieurs facteurs. Bien que ces deux contraintes semblent totalement opposées, plusieurs similitudes les relient. Parmi ces similitudes; le besoin en termes de télémédecine permettrait de suivre davantage les réponses physiologiques lors de ces deux contraintes (fig. 1.1). Cela permettrait également de mieux adapter les futures charges d'entraînement/travail que ce soit en réadaptation ou en contexte d'expédition afin de diminuer le risque de blessures et d'assurer une progression optimale. De plus, plusieurs risques similaires, mais dus à des causes différentes, relient les deux types de contraintes, soit les risques de perte de masse musculaire, l'augmentation des demandes énergétiques, de diminution des capacités cardiorespiratoires, les processus inflammatoires ainsi que l'isolement. Ces termes seront présentés à travers la problématique où une recension des écrits scientifiques situe ce qui est actuellement connu sur les adaptations physiologiques reliées aux contraintes présentées dans cette thèse ainsi que la méthodologie, où le besoin en télémédecine est mis de l'avant afin d'observer les réponses physiologiques. Par la suite, les articles composant cette thèse seront présentés, ainsi qu'une discussion synthèse des grandes observations des articles pour terminer par une conclusion regroupant les limites ainsi que les éléments les plus importants à retenir des recherches effectuées.

CHAPITRE I: PROBLÉMATIQUE

1.1. Pertinence

La télémédecine est une technologie prometteuse pour soutenir le système de la santé afin d'améliorer la qualité et l'efficacité des services de santé offerts (Craig and Patterson 2005; Maglaveras et coll. 2005). La télémédecine réfère à l'utilisation de technologie électronique et/ou de télécommunication afin de transférer de l'information médicale ou relier les bénéficiaires à la santé à distance. Elle est composée de six éléments essentiels (Bashshur, Reardon, and Shannon 2000):

a) une séparation géographique entre le fournisseur et le receveur d'information,
b) l'information par la technologie sert de substitut à un entretient face à face,
c) performer des actes professionnels en santé nécessaires (par exemple: médecin, techniciens, et thérapeutes),
d) une structure organisationnelle souhaitable pour le développement ou l'implantation d'un système ou un réseau,
e) protocoles cliniques correspondant à un traitement ou un triage de patients et
f) standards normalisés pour les médecins et administrateurs en regard à la qualité du soin, la confidentialité, etc.

Cette technologie peut être vital dans certains secteurs comme les milieux de travail extrême (par exemple: pompiers, employés du milieu forestier et les ouvriers en Antarctique), pour les services en santé en région éloignée, ainsi que les explorateurs en milieu extrême (Antarctique) et pour la réadaptation de patients à mobilité réduite, soit dans le cas présent, des patients atteints de MPOC (Craig and Patterson 2005; Dolezal et coll. 2014). Cette technologie, en plus de suivre les différentes réponses physiologiques, permettrait de diminuer les risques pouvant en découler tout en offrant des soins médicaux au besoin (Craig et Patterson 2005; Dolezal et coll. 2014) (fig. 1.1). L'utilisation de telle technologie permet de faire avancer la science ainsi qu'offrir un impact concret dans le soutien médical autant au niveau du système de santé qu'en aide aux explorateurs. La revue de littérature scientifique qui suit montre ce qui est déjà connu de ces deux contraintes afin de présenter par la suite ce qui a été possible d'observer et de proposer des recommandations en télémédecine pour le futur. La figure 1.1 illustre les grandes lignes de ce qui sera présenté à travers la thèse.

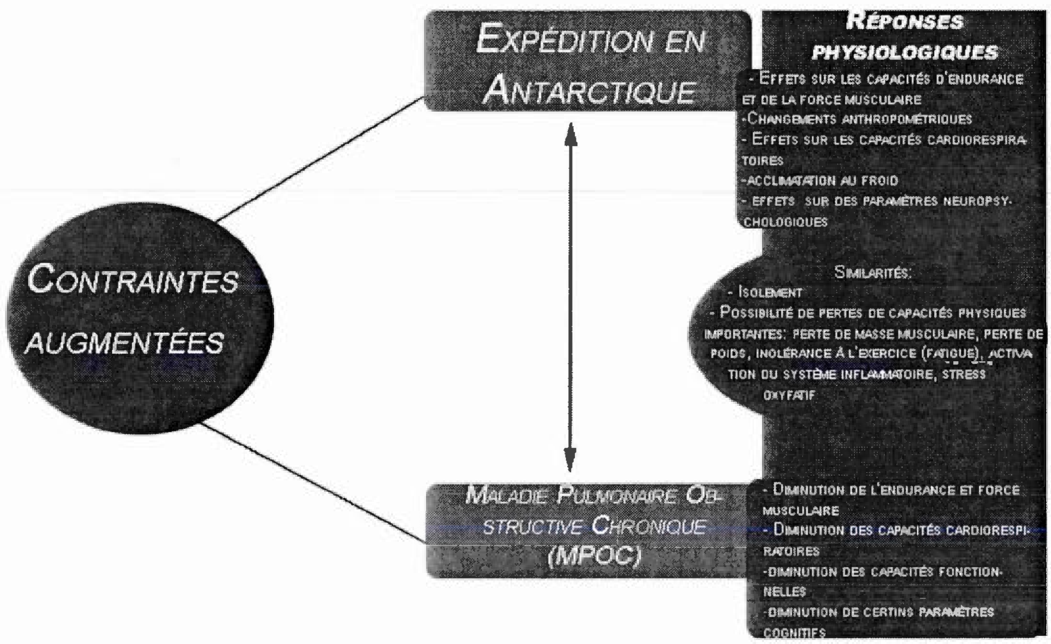

Figure 1.1:Schéma expliquant les liens physiologiques et besoins similaires entre les contraintes augmentées dû à un milieu extrême et les contraintes augmentées dues à une maladie pulmonaire obstructive chronique (MPOC) dans la littérature à ce jour.

1.2. État de la littérature scientifique

1.2.1. Contraintes augmentées en milieu extrême, l'Antarctique.

Réponses physiologiques en milieu polaire

Le milieu polaire est un environnement extrême où le corps humain est défié à tout moment. L'Âge d'or des explorations en milieu polaire a permis d'exposer ces défis, parfois avec des conséquences tragiques (Halsey et Stroud 2012). Depuis ce temps, plusieurs recherches ont permis de comprendre de nombreux mécanismes et proposer des solutions pour survivre dans ce milieu hostile. Toutefois, malgré les nouvelles connaissances et les avancées technologiques, le milieu polaire reste un environnement extrêmement dangereux causant encore aujourd'hui bien des conséquences fatales. Les paragraphes suivants préciseront les différentes réponses physiologiques observées en milieu polaire.

Capacité musculaire et aérobie reliée aux expéditions polaires

Une expédition polaire en complète autonomie exige des explorateurs qu'ils n'utilisent aucune aide mécanique ou animale pour transporter la totalité du matériel et de la nourriture dont ils ont besoin. Ils doivent donc transporter des charges élevées dans des sacs à dos et des traîneaux appelés Pulka, sur de longues heures où les déplacements s'effectuent majoritairement en ski (Frykman et coll. 2003; Halsey et coll. 2016; Van Marken Lichtenbelt et coll. 2014; Stroud 2001) De telles expéditions demandent des capacités musculaires élevées pour mener à bien les objectifs fixés par ces explorateurs. Toutefois, les conditions d'une expédition en complète autonomie engendrent des conséquences délétères sur les capacités musculaires. Frykman et coll.

(2003) ont observé chez deux hommes, après 3 mois d'expédition en complète autonomie en région polaire, une diminution marquée de la puissance au saut vertical ainsi que lors d'un test de Wingate sur vélo chez les deux explorateurs. Les auteurs ont également observé que chez le participant 1, l'endurance musculaire (nombre de répétitions maximal de squat avec une charge de 100lbs) avait diminué de 23 répétitions alors que le participant 2 s'était amélioré de 11 répétitions. Inversement, dans la même étude le participant 1 avait amélioré sa force maximale de 4.8 kg (1 répétition maximale d'un mouvement reproduisant une manœuvre de chargement), alors que le participant 2 avait une performance inférieure pre-post de -14.2 kg . Dans les deux cas, les pertes observées étaient plus importantes que les gains chez l'explorateur s'étant amélioré. Ces pertes de capacités ont été expliquées par les auteurs par l'apport énergétique qui était insuffisant. Cette conclusion est corroborée par les articles de Stroud (Halsey et Stroud 2012; Stroud 1998; Stroud 2001; Stroud, Coward, et Sawyer. 1993) où l'auteur a observé durant plusieurs expéditions la dépense énergétique de traversées polaires où les explorateurs étaient en complète autonomie.

Cette technique de progression en complète autonomie en milieu polaire demande l'utilisation d'un nombre important de muscles, incluant le tronc ainsi que les bras, durant plusieurs heures de progression, typiquement 10 à 12 heures par jour, sur plusieurs jours dans des conditions environnementales induisant une dépense énergétique importante (Frykman et coll. 2003; Halsey and Stroud 2012). Dans ces conditions la dépense énergétique se retrouve à être supérieure au nombre de rations pouvant être transportées afin de combler cette perte énergétique (Frykman et coll. 2003; Halsey et Stroud 2012). Ce déficit énergétique engendre une diminution des réserves des explorateurs (% de gras corporel, de réserve de glucides et à l'extrême de protéines) menant à la consommation de tissus vitaux, dont le muscle (Stroud 1998), expliquant possiblement une diminution de la force (Stroud 2001). De plus, Schantz et coll. (1983) a observé chez des fondeurs ayant un volume de travail en endurance important un changement dans la typologie musculaire où les fibres de type 1, fibres lentes étaient favorisé, ainsi qu'une dégradation sélective des fibres de type 2, fibre rapide, expliquant la détérioration de la puissance musculaire. Toutefois, un changement significatif dans l'histologie n'a pas été détecté chez les explorateurs durant une expédition de 42 jours en ski (Helge et coll. 2003), possiblement dû au nombre restreint de 4 participants. Ces changements musculaires ont également un impact sur la capacité aérobie. Stroud (2001) a observé une diminution de la capacité aérobie après 95 jours d'expédition en Antarctique en complète autonomie. Il en était de même pour Brotherhood et coll. (1986) pour 9 hommes après 69 jours d'expédition en Antarctique. Toutefois, Frykman et coll. (2003) a observé des données contradictoires où l'un des explorateurs s'est amélioré alors que l'autre avait une VO_2max inférieure après l'expédition.La dégradation en L/min était plus importante que le gain obtenu par l'autre explorateur, soit une amélioration de 0.17 L/min et une détérioration de -0.84 L/min. Toutefois, il est à noter que lorsque la VO_2max a été comparée en fonction du poids corporel le gain et la perte étaient dans les deux cas de +/- 3,7 ml/kg/min, mais les auteurs n'ont pas comparé ces valeurs en fonction de la masse maigre des explorateurs. Ce dernier point pourrait jouer un rôle important sachant que la masse musculaire de la masse maigre est un facteur important dans la consommation de l'oxygène. D'ailleurs, l'explorateur ayant une amélioration de sa capacité aérobie avait une masse maigre supérieure après l'expédition et grâce aux données présentées il est possible de noter une augmentation de 1.8 ml/kg de masse maigre/min. Alors que pour l'explorateur ayant une perte de capacité aérobie, une masse musculaire inférieure après l'expédition fût observée où la perte calculée est de -9.7 ml/kg de masse maigre/min. Ces données corroborent encore une fois les observations de Stroud (Halsey et Stroud 2012; Stroud 1998; Stroud 2001) où l'importance dans les changements anthropométriques semble être reliée aux diminutions de capacités physiques après l'expédition.

Anthropométrie et thermorégulation en milieu froid

La composition corporelle est un élément important en contexte d'expédition polaire. Comme brièvement introduite plus tôt, la balance énergétique entre la dépense énergétique excessivement élevée et la consommation des rations ne permet pas de maintenir un équilibre dû à la quantité trop élevée de nutriment qui devrait être transporté (Halsey et Stroud 2012). Cet équilibre énergétique négatif exige que le corps humain puise son énergie dans les réserves de gras et de protéines, car les réserves de glucides s'épuisent rapidement. Lorsque les réserves d'énergies en gras et en protéine s'épuisent, le corps n'a plus le choix d'aller puiser l'énergie des tissus vitaux, ce qui a comme conséquence une détérioration des fonctions physiologiques (Halsey et Stroud 2012). C'est pourquoi les études antérieures observent d'importantes pertes de poids, de % de gras corporel et bien souvent de masse maigre, ainsi qu'une perte de capacité fonctionnelle (Brotherhood et coll. 1986; Campbell 1981; Frykman et coll. 2003; Halsey et Stroud 2012; Stocks et coll. 2004; Stroud 2001). Deux problèmes majeurs accompagnent la perte de pourcentage de gras excessive en milieu polaire : l'augmentation des risques d'hypothermie et la diminution des capacités physiques (Halsey et Stroud 2012). Les réserves de gras jouent un rôle significatif pour contrer la perte de chaleur, servant d'isolant dû à la propriété du tissu adipeux d'être moins conducteur d'énergie et à la vascularisation moindre (Ducharme et Tikuisis 1991). Sans cette protection, la perte de chaleur enclenche des mécanismes afin de garder la température corporelle stable, dont la contraction des muscles, produisant le grelottement afin de produire de la chaleur (Bell, Tikuisis, et Jacobs 1992; Castellani et coll. 2006). La perte de masse musculaire joue un rôle également dans les derniers stades de l'hypothermie où cette perte de masse musculaire et par le fait même une réserve de glucide presque épuisé résultera en une hypoglycémie, menant à l'utilisation d'autre substrat énergétique dans le système nerveux central comme la ketone et le lactate par le corps humain (Stroud 1998). Le niveau de ces substrats est très limité et résultera rapidement en une incapacité du corps humain à fonctionner correctement, pour finalement arriver à un point où le métabolisme ne produira plus suffisamment de chaleur, menant à l'hypothermie et finalement la mort (Halsey and Stroud 2012).

Le sexe joue également un rôle important dans le type de protection par le tissu adipeux. McArdle et coll. (1984) a observé que pour une femme comparée à un homme ayant un taux adipeux similaire, la femme aura une réduction plus importante de sa température corporelle. Quelques hypothèses ont été émises pour expliquer ce phénomène; le ratio masse et surface corporelle, la différence dans la composition du tissu adipeux entre homme et femme. Toutefois, chez l'homme, l'individu ayant un pourcentage de gras plus élevé sera en mesure d'atteindre la température corporelle d'homéostasie sans grelottement lors d'exposition à des températures plus froides que l'homme ayant un pourcentage de gras plus faible (McArdle et coll. 1984). D'ailleurs Kollias et coll. (1974) ont observé qu'une femme, qui possède naturellement un pourcentage de gras plus élevé, comparé à un homme dans un percentile anthropométrique similaire, avait un taux similaire de refroidissement. Montrant ainsi que la thermorégulation est un mécanisme complexe et ne résulte pas seulement du pourcentage de gras. Par exemple, chez la femme le cycle menstruel et la régulation hormonale ont un important impact sur la température corporelle, la perception de la température, la circulation et la régulation des électrolytes (Cabanac, Cunningham, and Stolwijk 1971; Grucza, Pekkarinen, and Hänninen 1999; Hessemer and Brück 1985; Hirata et coll. 1986). Durant une exposition au froid, les femmes ont généralement une température cutanée plus basse que chez les hommes et cela même à l'effort (Cabanac, Cunningham, et Stolwijk 1971; Walsh and Graham 1986). Toutefois, elles maintiennent un débit sanguin au niveau de la peau inférieure aux hommes, elles ont une plus grande résistance à la perte de chaleur et donc un gradient de température peau-environnement moindre exposé au froid (Fox et coll. 1969). L'âge peut aussi influencer la thermorégulation et le confort thermique perçu, où les enfants et personnes âgées sont désavantagés (Stocks et coll. 2004)

Réponses, acclimatation au froid et impact de l'altitude en milieu polaire

Les réponses et acclimatations aux froids ont fait l'objet de plusieurs recherches. Parmi les principales réponses aux froids, la sensation de douleur et d'inconfort sont particulièrement étudiés, majoritairement pour son acclimatation rapide après exposition répétée au froid (Makinen 2010). Après plusieurs expositions au froid, le frissonnement et la réponse à la vasoconstriction sont atténués, la diminution de la co-activation des muscles (frissonnement) pourrait être due à des changements du métabolisme et à la diminution des réponses neurologiques incluant des mécanorécepteurs sensoriels et les transmissions neurales, toutefois les mécanismes de cette acclimatation restent incertains. La diminution de la performance physique ainsi que la diminution de performance cognitive, de vigilance et psychomotrice ont été également observées et possiblement relié à la sensation d'inconfort lors d'exposition au froid. Toutefois, l'acclimatation ou l'adaptation possible après ce type d'exposition semble plus difficile à observer et demeure aujourd'hui très controversée (Makinen 2010).

La puissance et la force musculaire lors d'exposition au froid ponctuel diminuent significativement possiblement dû aux changements des fonctions neuromusculaires (Oksa et coll. 1995) . Il a été également observé au niveau neurologique que les performances cognitives peuvent être détériorées telles que l'attention qui était diminuée lors de tâches en exposition au froid, possiblement dû en partie à l'inconfort par la perception du froid (Makinen 2010). La diminution de la force combinée à l'attention diminuée, due en partie à des détériorations du système nerveux, peut mener à des temps de réaction trop lents face au danger pouvant contribuer à augmenter les risques d'accident (Makinen 2010).

Le froid a également un impact sur les capacités cardiorespiratoires. Il est possible d'observer lors d'exercice au froid; une fréquence cardiaque plus basse, une ventilation plus élevée, une pression artérielle plus élevée pour une même intensité à température tempérée (Doubt et Smith 1990; Vogelaere et coll. 1986).Toutefois, la consommation en oxygène (VO_2) semble être un sujet controversé à l'exercice. Bien qu'il est consensus sur une VO_2 de repos plus élevé qu'en température tempérée (environ 50% de la VO_2max (Eyolfson et coll. 2001)), la VO_2 à l'exercice en milieu froid semble variée selon l'intensité et le temps où parfois la VO_2 est plus élevée ou sans différence significative en comparaison à une même intensité en milieu tempéré (Castellani et coll. 2006; Ducharme and Brajkovic 2005; Horvath 1981). Il a également été observé qu'une bronchoconstriction à l'effort en milieu froid pouvait mener à des symptômes similaires à l'asthme pour certains athlètes pratiquant un sport de haute intensité en milieu froid (Larsson et coll. 1993; Wilber and Rundell 2000). Cette limitation à la performance peut être limitée par l'utilisation d'un foulard afin de garder la chaleur et la vapeur d'eau de la respiration, mais peut devenir aussi un élément de restriction respiratoire (Giesbrecht 1995).

Pour une même altitude sur le plateau polaire, la pression atmosphérique et donc la pression partielle d'oxygène chez l'humain sont moindres que sur les autres continents, réduisant d'environ 30% l'air disponible à l'organisme pour performer sur le plateau. Pour une dénivellation de 2300m sur le plateau antarctique, le pourcentage d'oxygène sera équivalent à environ 2800m de dénivellation sur les autres continents (Halsey et Stroud 2012). Deux hypothèses ont été proposées soit; le froid extrême réduirait la troposphère, augmentant le taux à laquelle la pression atmosphérique diminue avec l'altitude (West 2001); et la possibilité qu'un vortex soit créé par la présence des grands vents diminuant la pression (Halsey et Stroud 2012). De plus, d'importantes détériorations de la performance peuvent être observées à partir de 1500 m d'altitude(Bärtsch et Saltin 2008). Une courte exposition à partir de 1500 m d'altitude provoque une élévation de la ventilation et la de fréquence cardiaque causé par, mais par l'effet de la stimulation des chimiorécepteurs sanguins à la diminution de la pression atmosphérique déjà apparente à 1500 m d'altitude. La performance aérobie diminue et la saturation de l'hémoglobine à l'oxygène diminue significativement à l'exercice limitant l'effort produit déjà à 1500 m d'altitude (Bärtsch et Saltin 2008). D'autres épiphénomènes reliés à un séjour en haute altitude sont reliés au sommeil, la récupération à l'effort, ainsi que l'appétit sont perturbés et peuvent avoir des conséquences sur les risques de blessures (Bärtsch et Saltin 2008). Des impacts similaires ont été observés entre cet état d'hypoxie et les personnes atteintes de maladies pulmonaires obstructives chroniques (MPOC) tels que débalancement défavorable de la balance énergétique, la perte de poids, notamment la perte de masse musculaire, ainsi qu'une augmentation du métabolisme de repos (Agustí et coll. 2003)

Possibles contremesures grâce aux avancés technologiques et scientifiques

Il a été mentionné précédemment que la balance énergétique négative était un aspect déterminant à la perte de capacité physique, c'est pourquoi une des contremesures consiste en une diète riche en gras. Les premières études proposaient des rations riches en protéines dues à la perte de masse musculaire (Campbell 1981; Halsey et Stroud 2012). Toutefois, sachant la dépense énergétique due à la digestion des protéines ainsi que l'énergie disponible à être utilisée, les lipides et glucides sont de meilleurs choix afin d'équilibrer au mieux la balance énergétique lors d'une expédition (Halsey et Stroud 2012). Les expéditions récentes utilisent en majorité lipide et glucide pour leur ration, par contre deux problèmes se posent; quelle est la composition la mieux adaptée aux expéditions polaires; et comment s'assurer que les explorateurs respecteront les consignes ssur la quantité et de contenue pour ce type de diète (Halsey et Stroud 2012; Stroud 1998)

Bien que la nourriture joue un rôle important, les nouvelles technologies ainsi que la préparation physique restent également des enjeux importants, afin d'assurer la sécurité et le succès de l'expédition. Les nouvelles technologies permettent d'utiliser des équipements plus légers et plus efficaces pour protéger du froid, du vent et de l'humidité. Les vêtements en sont un bon exemple, des études antérieures ont observé une dépense énergétique importante due au poids et aux restrictions de mouvements des vêtements (Teitlebaum and Goldman 1972). L'étude de Teitlebaum et Golman (1972) a observé une augmentation d'environ 16% de la consommation en oxygène (VO_2) pour une même vitesse sur un tapis roulant avec des vêtements comparé au même poids portée à la ceinture. Les auteurs expliquent cette différence probablement due à la friction entre les différentes couches de vêtements utilisés lors d'expédition polaire. Il en est de même pour les traîneaux et les skis utilisés où la friction peut varier en fonction du type de neige, les nouvelles technologies permettent de réduire certains types de friction en fonction du type de neige (Brotherhood et coll. 1986; Frykman et coll. 2003; Simpson 2010). Finalement, la préparation physique ne peut être mise de côté avant une expédition, parmi les préparations; une augmentation du % de gras permet de former des réserves de gras suffisantes à contrer la balance énergétique négative pouvant survenir durant l'expédition (Halsey et Stroud 2012). De plus, afin d'être en mesure de soutenir la poussée des traîneaux avec un surplus de poids corporel (réserves de gras), surtout lors de l'ascension d'un plateau en début d'expédition où la pente peut être très inclinée et que les traîneaux sont les plus lourds dus aux rations, les explorateurs doivent être en mesure de soutenir l'exercice sur plusieurs heures, voir des jours selon les conditions météorologiques et les objectifs de l'expédition. Frykman et coll. (2003) ont estimé une épreuve similaire à environ 28.3-34.5 MJ/jour. De plus, la poursuite de l'expédition demande un minimum dû à la fatigue qui s'accumule, à la perte de capacité fonctionnelle et l'alimentation insuffisante en calories, mais également vitamine et minéraux (Frykman et coll. 2003; Hoyt et coll. 1991, 1994)

1.2.2. .Contraintes augmentées en situation de maladie pulmonaire obstructive chronique (MPOC)

Réponses physiologiques dues à la MPOC

La MPOC est un problème public majeur mondial, majoritairement dans les pays industrialisés où l'importance de la cigarette, tabagisme dans le mode de vie est un facteur de risque important. Cette maladie est la quatrième cause de mortalité dans le monde (Pauwels et coll. 2012). C'est pourquoi un effort international était nécessaire afin de comprendre et proposer de nouvelles solutions à ce problème. Le Global Initiative for Chronic Obstructive Lung Disease (GOLD) est un projet collaboratif entre le US National Heart Lung, and Blood Institute et le World Health Organization (Pauwels et coll. 2001). Le but étant l'amélioration de la compréhension et la diminution de la morbidité de la MPOC par le biais d'une concertation mondiale afin d'améliorer la prévention et la gestion de cette maladie (Pauwels et coll. 2001). C'est grâce à cette initiative que la majorité des recommandations utilisées aujourd'hui en réadaptation pulmonaire ont pu être émises.

Qu'est-ce qu'une maladie pulmonaire obstructive chronique (MPOC)?

La MPOC se définit comme étant un état pathologique caractérisé par une limitation du débit d'air qui n'est pas entièrement réversible, généralement progressive et associé à une réponse inflammatoire anormale des voies aériennes à des particules ou gaz nocifs (Pauwels et coll. 2012). Le diagnostic est confirmé en mesurant la capacité vitale forcée à l'aide d'une spirométrie. Une capacité vitale forcée se veut la référence comme évaluation des fonctions respiratoires et consiste en une inspiration maximale suivie d'une expiration maximale selon un protocole standardisé (Wanger et coll. 2005).

La classification de la sévérité de la maladie selon l'American Thoracic Society (ATS) est faite selon ce qui est présenté au tableau 1.2-1. Différentes mesures permettent de faire la classification et impliquent différents paramètres de la spirométrie, dont la capacité vitale (CV) et le volume expiratoire maximal en 1 seconde (VEMS).

Tableau1.1:Classification de la MPOC par sévérité

Niveau de sévérité	Léger Stage 1	Moyen Stage 2	Sévère Stage 3	Très sévère Stage 4
% VEMS selon la valeur prédite	≥ 80%	≤ 50%->80%	≤ 30%->50%	<30%
VEMS/CV		≤ 0.7 pour tous les stades		

La pathologie

Bien que les MPOC sont composées de différents facteurs contribuant à la pathologie, le terme MPOC englobe deux conditions : l'emphysème et la bronchite chronique (Thomas, Decramer et O'Donnell 2013).

Emphysème

L'emphysème est caractérisé par des dommages irréversibles du parenchyme et de la vascularisation adjacente du poumon. Il a même été suggéré récemment que l'oblitération et le rétrécissement des bronchioles terminales pourraient précéder le développement d'un emphysème destructif (Thomas, Decramer et O'Donnell 2013). Deux formes distinctes d'emphysème sont décrites dans la littérature : l'emphysème centrolobulaire est souvent relié aux fumeurs et l'emphysème panlobulaire est une maladie génétique rare qui touche environ 1% des cas d'emphysème. L'emphysème centrolobulaire (figure 1.2 a) a comme principal site d'inflammation et de destruction les bronchioles respiratoires, dans un cas de maladie avancée, le lit capillaire peut aussi être touché. Cette forme d'emphysème est plus fréquemment observée dans les lobes supérieurs dans sa forme bénigne (Szilasi et coll. 2006)

L'emphysème panlobulaire (figure 1.2 b) est typiquement une déficience du α-antitrypsin, les conduits et les sacs alvéolaires sont impliqués dans le processus de la maladie. Elle est majoritairement localisée dans les lobes inférieurs (Szilasi et coll. 2006).

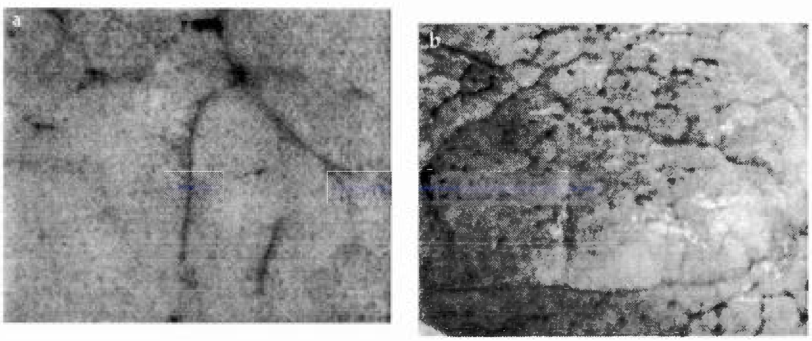

Figure 1. 2 : a) Emphysème centrolobulaire et b) emphysème panlobulaire (Szilasi et coll. 2006)

Le débalancement protéase/antiprotéase est en cause dans le développement de l'emphysème pulmonaire. L'inflammation est principalement due par le $CD8^+$ des lymphocytes T. Les macrophages et neutrophiles produisent excessivement de protéases incluant les leucocytes elastase, cathepsine G, protéinase 3, MMPs, cystéine protéinase et plasminogen activateur (fig 1.3), menant à la destruction de la paroi des alvéoles et de la matrice et donc à une dysfonction du système respiratoire.

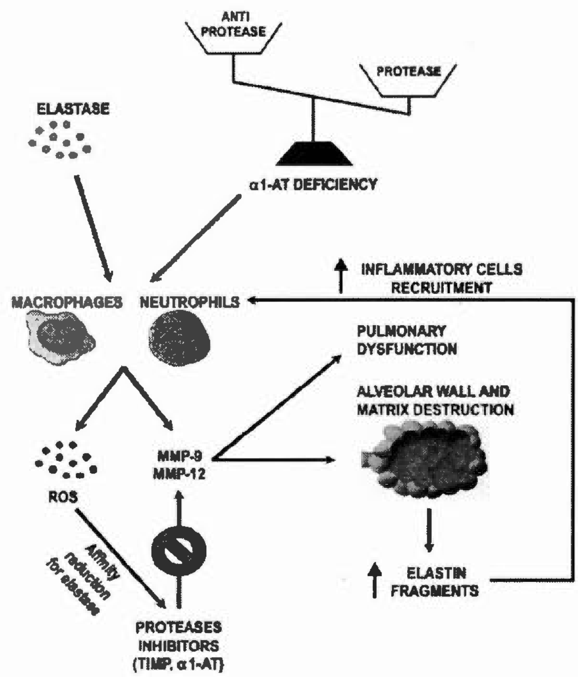

Figure 1. 3: Voie de signalisation de l'emphysème panlobulaire (Antunes and Rocco 2011)

Bronchite chronique

La bronchite chronique est caractérisée par l'obstruction des voies respiratoires résultant d'une inflammation et remodélisation des voies respiratoires par l'oedème et de l'augmentation de mucus (Thomas, Decramer et O'Donnell 2013). D'ailleurs, Thurlbeck (1990) décrit la morphologie de la bronchite chronique comme étant associé à l'excès de mucus dans les voies aériennes ce qui engendre un rétrécissement de la lumière dû au mucus et un épaississement des parois des voies respiratoires en raison des ganglions et possiblement de l'oedème inflammatoire (fig 1.4). Cette hypersécrétion est le résultat de métaplasie des cellules à mucus (fig 1.5). Ces cellules remplacent les cellules de Clara et les cellules séreuses dans les petites voies respiratoires, engendrant une production dominante de mucus sur la sécrétion surfactant (Szilasi et coll. 2006). En outre, on observe que l'inflammation péribronchiale pour les fumeurs avec MPOC ont un nombre de CD8+ lymphocyte T supérieur en comparaison à un groupe de fumeurs sans MPOC. D'ailleurs, le macrophage et les CD8+lymphocyte T dominent l'inflammation des petites voies respiratoires (Szilasi et coll. 2006).

Figure 1. 4: Image d'hypersécrétion de mucus chez un patient atteint de bronchite chronique au niveau de la bronche lobaire inférieure et de la bronche segmentaire (Thurlbeck, 1990)

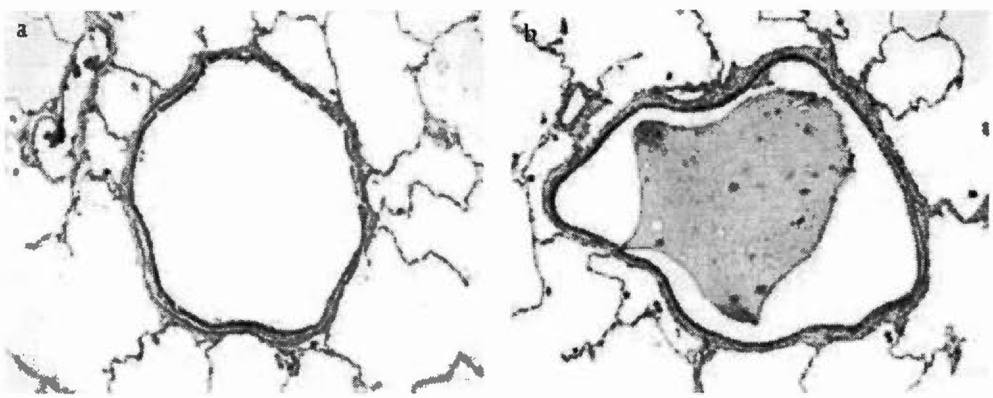

Figure 1. 5: Hypersécrétion de mucus remplissant l'alvéole dû à une bronchite chronique, l'alvéole en est déformée. La partie a est la lumière d'une alvéole saine et la partie b celle d'une personne atteinte de MPOC (Szilasi et coll.2006)

Les conséquences de la maladie?

La MPOC a d'importantes conséquences physiologiques et psychologiques. Les changements dans la vie quotidienne des patients touchés par la MPOC engendrent une diminution des capacités physiques, une diminution de la qualité de vie et une augmentation de risque de dépression (Laurin et coll. 2012; Paz-Diaz et coll. 2007). Traditionnellement, la diminution des capacités physiques était expliquée par l'augmentation du travail respiratoire et le l'hyperinflation dynamique résultant de la limitation respiratoire (Agustí et coll. 2003). Par contre, des études récentes ont dévoilé d'autres limitations physiologiques qui demandent à être prises en compte lors du traitement de cette maladie (Agustí et coll. 2003).

Hyperinflation dynamique

Traditionnellement, l'hyperinflation dynamique réfère à un état temporaire et variable de l'augmentation du volume du poumon pulmonaire totale de la valeur habituelle mesurée au repos lors d'une augmentation de la ventilation causée par l'exercice physique (O'Donnell 2006; O'Donnell et coll. 2012). Les conséquences mécaniques de l'hyperinflation dynamique à l'exercice sont complexes et varie d'un patient à l'autre (Thomas, Decramer et O'Donnell 2013). Chez un participant sans pathologie pulmonaire (voies aériennes et parenchyme pulmonaire non-affectés), le poumon durant l'exercice reste relativement constant à la fin d'une expiration (aucune hyperinflation dynamique). Toutefois, chez un patient atteint de MPOC durant l'exercice, le volume du poumon à la fin de l'expiration augmente durant la durée de l'effort (hyperinflation dynamique), dû à la difficulté à l'expiration (emprisonnement de l'air) causée par une résistance élevée à la circulation de l'air au niveau des voies aériennes. Ce phénomène pousse le volume courant de plus en plus près de la capacité totale du poumon où l'extension est limitée par la pression élevée. La respiration devient donc restreinte et le patient n'arrive plus à soutenir l'exercice (fig 1.6). L'exacerbation chez les patients MPOC occasionnels de la maladie est une cause importante dans la limitation à l'effort. L'hyperinflation peut mener à des conséquences précoces de fatigue musculaire et des muscles respiratoires voir même un arrêt des muscles respiratoires (Coussa et coll. 1993). Les facteurs derrière les mécanismes de l'exacerbation découlent de la relation complexe entre la consommation d'oxygène, le débit cardiaque et le déséquilibre ventilation/perfusion devant être considéré ensemble afin d'offrir un traitement efficace lors d'exacerbation chez les patients MPOC (Barbera et coll. 1997).

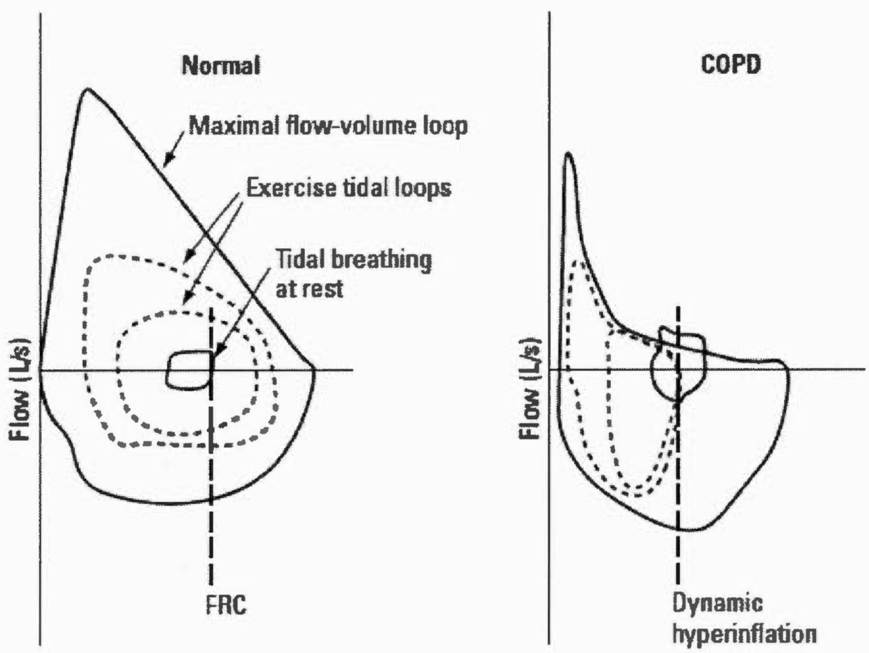

Figure 1. 6: Courbes débit volumes superposées (repos, exercice maximal et lors d'une spirométrie) durant un exercice progressif d'une personne atteinte de MPOC. Le trait vertical identifié par FRC indique la capacité résiduelle fonctionnelle (CRF) (Talag and Wilcox 2008).

Autres limitations à l'exercice

L'exercice reste un important moyen de contrer cette perte de capacité physique. Les raisons liées à cette perte de capacité physique sont bien plus complexes et touchent une multitude de systèmes que ce qui était traditionnellement perçut (fig 1.7). Les premières explications sur les limitations à l'exercice étaient reliées uniquement à la limitation respiratoire où découlait l'augmentation du travail respiratoire et l'hyperinflation dynamique expliquée précédemment. Par contre, depuis quelques années une approche systématique a été proposée par Agusti et coll. (2003). Cette approche montre plusieurs interrelations des systèmes affectés par la MPOC. Parmi ces différents systèmes, le système musculaire squelettique, immunitaire, cardiaque et nerveux semblent être touchés et jouer un rôle dans la limitation à l'exercice. Ces atteintes à ces différents systèmes perturbent les muscles périphériques qui sont particulièrement touchés chez les patients MPOC ce qui limite leur qualité de vie.

Muscles périphériques

Plusieurs études observent un dysfonctionnement des muscles squelettiques chez des patients MPOC (Agustí et coll. 2003; Maltais et coll. 1996; Sala et coll. 1999; Vonbank et coll. 2012). Ces observations furent déterminantes dans le cadre des recommandations en réadaptation, où les limitations à l'exercice étaient exclusivement dues à la limitation respiratoire. D'ailleurs, Killian et coll. (1992) ont observé plusieurs patients atteints de MPOC arrêter l'exercice dû à une fatigue musculaire au lieu de l'inconfort lié à la dyspnée, corroborant les études de Maltais et coll. (1996) qui ont observé une dysfonction importante du muscle squelettique, expliqué à ce moment seulement par le manque d'accessibilité à l'oxygène dû à la compétition entre la respiration et les demandes des muscles périphériques. Plusieurs études ont suivi confirmant une anomalie au niveau des muscles périphériques, toutefois les mécanismes ne sont pas totalement compris (Agustí et coll. 2003). Pour l'instant 2 phénomènes sont retenus: 1) la perte de masse musculaire et 2) le mal fonctionnement du muscle, possiblement dû à des altérations au niveau des mitochondries et de la perte de contractilité des protéines, ou au milieu où le muscle travail (hypoxie, hypercapnie et acidose) altérant les échanges gazeux (Agusti and Barbera 1994). De plus, la perte de masse musculaire est aussi observée chez des sujets en environnement hypoxique comme l'altitude et pourrait en partie expliquer les mécanismes d'hypoxie sur les muscles périphériques où une exposition chronique à l'hypoxie supprime la synthèse protéique des muscles squelettiques, cause une perte d'acide aminé et réduit l'expression de l'isoforme de la chaîne lourde de myosine. D'ailleurs, il a été observé que la force des muscles périphériques est réduite chez les patients ayant une MPOC et est corrélée fortement avec l'intensité des symptômes et la capacité de travail. Les modalités d'entraînements et protocoles varient énormément d'une étude à l'autre, mais propose majoritairement un entraînement en endurance, pourtant ce type d'entraînement ne transmet pas ou peu d'amélioration de la qualité de vie (Benton et Wagner 2013). D'ailleurs, il semble qu'un entraînement en force serait plus efficace qu'un entraînement en endurance afin d'observer une augmentation de la capacité à l'exercice et la qualité de vie (Vonbank et coll. 2012). Toutefois, le lien entre l'augmentation de la force et l'amélioration de la qualité de vie semble controverser (Benton et Wagner 2013). Néanmoins, les études s'entendent sur l'importance de l'entraînement dans le cadre de la réadaptions pulmonaire étant donnée la perte de capacité physique les patients atteints de MPOC ont tendance à adopter un mode vie plus inactif et à diminuer davantage leur condition physique, formant ainsi un cercle vicieux, augmentant davantage la fatigue face aux tâches quotidiennes et diminuant la qualité de vie.

Perte de poids et métabolisme de base plus élevée

La perte de poids est un autre déterminant important, majoritairement dû à la perte musculaire, ajoutant un poids aux dysfonctions musculaires. Des changements au niveau du métabolisme de base, des altérations au niveau de la prise alimentaire et la composition corporelles sont observés, mais reste incertains quant aux mécanismes exacts. La perte de poids semble être due à une forme de « cachexie », où le patient prend un nombre de calories apparemment suffisantes, voir même au-dessus de ce qui est requis tout en perdant du poids (Baarends et coll. 1997; Hugli, Schutz, et Fitting 1996). Les critères de cachexie incluent une perte de poids involontaire ≥5%, une diminution de la masse maigre, une présence systémique inflammatoire tels que les cytokines pro-inflammatoires et marqueur inflammatoire ainsi qu'un taux d'albumine inférieur à 35g/L (Morley, Thomas, et Margaret-Mary 2006). Les mécanismes de cachexie chez les patients MPOC restent inconnus, toutefois l'inflammation systématique semble jouer un rôle important dans la perte de masse musculaire et l'augmentation du métabolisme qui toucherait 15-26% des patients MPOC (Marieve Doucet 2008). L'augmentation du métabolisme de base en dessous de ce phénomène reste incertaine, basée au départ par l'augmentation de la demande énergétique lors de la respiration, cette hypothèse seule ne tenait plus lorsque des chercheurs ont observé une bioénergétique anormalement élevée au niveau de muscles non respiratoires (Jakobsson et Jorfeldt 1992; Kutsuzawa et coll. 1995; Wuyam et coll. 1992).Toutefois, l'inflammation systématique semble être l'hypothèse la plus probable selon la littérature (Broekhuizen et coll. 2006; Creutzberg et coll. 2000; Yoneda et coll. 2001). L'étude de Doucet et coll (2010) proposait d'ailleurs l'augmentation du catabolisme musculaire, où l'expression atrogin-1, de MuRF1 et la forme phosphorylée d'AKT, 4E-BP1 et FoxO-1 serait plus élevé chez les patients MPOC comparés à un groupe contrôle. De plus, l'expression de p70 S6K , GSK-3J3 et 4E-BP1 étaient plus élevés chez les patients MPOC avec atrophie musculaire que le groupe sans atrophie (Doucet et coll 2010). Toutefois, ces mécanismes ont fait l'objet de plusieurs critiques et demanderaient davantage de recherche afin de conclure aux mécanismes d'hypermétabolisme.

Réponses inflammatoires

Finalement les réponses inflammatoires du parenchyme du poumon causent d'importantes conséquences par son inflammation systématique incluant un stress oxydatif systématique, une activation des cellules inflammatoire en circulation et l'augmentation du niveau de cytokines pro-inflammatoires (Barceló et coll. 2006; Drost et coll. 2005).

D'autres limitations peuvent s'ajouter chez certains patients atteints de MPOC tel que des maladies coronariennes, un risque accru d'ostéoporose, des altérations au cerveau ou certaines anomalies du système nerveux autonome (Agustí et coll. 2003). C'est pourquoi la place de l'activité physique dans le mode de vie d'un patient MPOC joue un rôle important dans le maintien des capacités fonctionnelles, mais aussi dans la diminution des risques de développer une/des comorbidités.

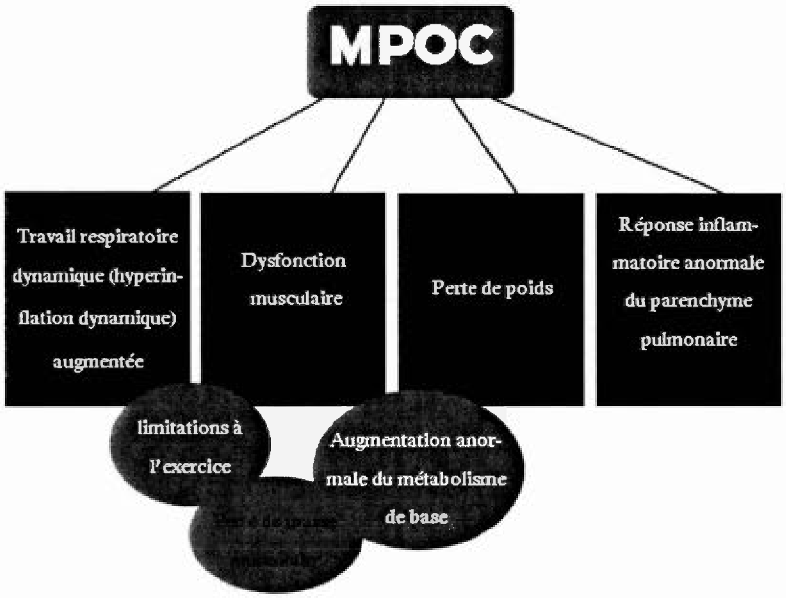

Figure 1. 7: Les effets systématiques de la MPOC, adaptée du tableau d'Agusti et coll 2003

Quel est l'impact sur leur qualité de vie?

La qualité de vie des patients atteints de MPOC est gravement touchée, plus particulièrement lorsque la maladie est à un stade sévère (Monsó et coll. 1998; Peruzza et coll. 2003). Dans leur cas la perte de capacité est accompagnée également d'une déficience de réaction émotionnelle, qui se réfère à une dysrégulation des réactions émotives conventionnellement acceptée, et du sommeil. La dégénérescence de la qualité de vie est souvent représentée sous forme de cercle menant à une dégradation accrue de plus en plus importante. La perte de qualité de vie peut être présentée via différents aspects comme illustrés à la figure 1.8 (Casanova et coll.

2008; Clark, Cochrane, et Mackay 1996; Dodd, Getov et Jones 2010; Gardiner et coll. 2009, ; Miravitlles et coll. 2009; Monsó et coll. 1998; O'Donnell et coll. 2012; Peruzza et coll. 2003; Pinto-Plata et coll. 2004; Puhan et coll. 2013; Quint et coll. 2008; Serres et coll. 1998; Yohannes et coll. 1998): la perte de capacité fonctionnelle, l'isolement social pouvant mener à de la dépression et/ou de l'anxiété ce qui pourrait expliquer l'aspect psychologique de la qualité de vie qui est parfois accompagnée de déficience au niveau des émotions et du bien-être, suivi d'un mode de vie plus inactif contribuant à la détérioration des capacités physiologiques. De plus, la détérioration des capacités fonctionnelles est hautement corrélée à la mortalité chez les patients atteints de MPOC, particulièrement liés aux résultats au test de marche de 6 minutes ainsi que le relevé de chaise (Casanova et coll. 2008; Pinto-Plata et coll. 2004; Puhan et coll. 2013). (fig 1.8)

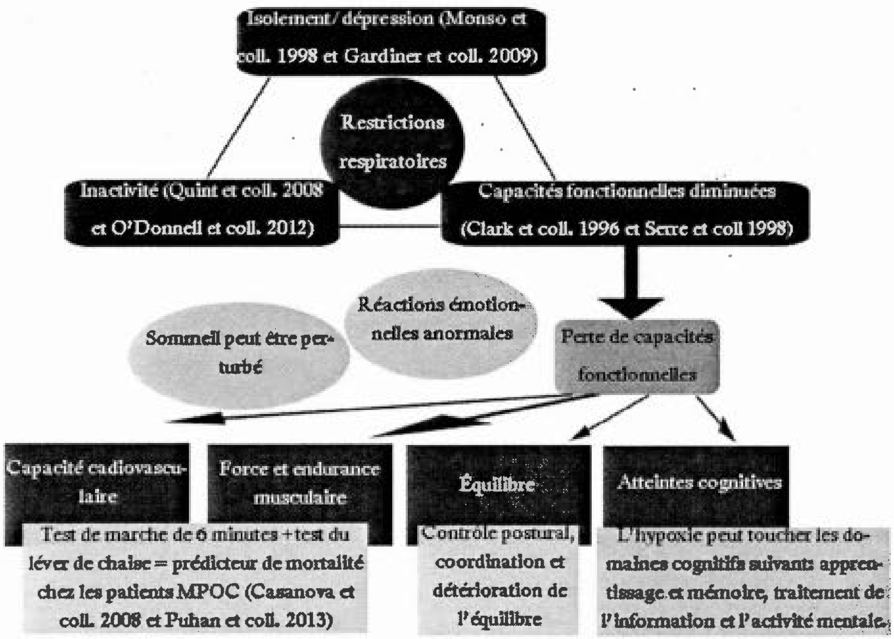

Figure 1. 8: Graphique illustrant le cercle menant au déconditionnement d'un patient MPOC et des pertes de capacités fonctionnelles en découlant

Quelles sont les recommandations pour la réadaptation de la COPD

Les patients atteints de MPOC peuvent répondre différemment à l'exercice selon le stade et la cause de la maladie. C'est pourquoi les recommandations pour la réadaptation de cette population débutent par l'évaluation des capacités du patient (Gloeckl, Marinov et Pitta 2013). Parmi ces évaluations il est recommandé de proposer un test cardiopulmonaire à l'exercice par incrément, un test cardiopulmonaire à charge constante, le test de marche de 6 minutes, le test de relevée de chaise et un test de force des muscles périphériques (Gloeckl, Marinov et Pitta 2013). Ces tests permettront de prescrire plus précisément la charge de travail du programme proposé. Les programmes de réadaptation pulmonaire conventionnels recommandent habituellement (Gloeckl et coll 2013) un entraînement en endurance cardiorespiratoire de 3 à 4 séances de 10 à 40 minutes par semaine selon la condition de santé des patients MPOC. L'intensité de cette séance est de 60-80% de la capacité maximale du patient lors d'une séance d'entraînement cardiorespiratoire en continu et de 80% à 150% pour des intervalles de 20 à 30secondes

.

L'entraînement en endurance cardiorespiratoire a pour but principal d'améliorer la capacité aérobie ainsi que la fonction des muscles périphériques. Ce dernier peut-être fait sous forme continu ou par intervalle, tout dépendant de la capacité du patient. Il est à noter que plusieurs patients atteints de MPOC ne peuvent soutenir un exercice de haute intensité dû à différents symptômes comme la dyspnée et la fatigue (Gloeckl, Marinov et Pitta 2013; Puhan et coll. 2013). Toutefois, il semble que l'entraînement par intervalle permet aux patients MPOC sévères d'augmenter nettement le total de temps d'exercice par un stress ventilatoire moindre, ainsi qu'une diminution d'hyperinflation dynamique à l'exercice (Vogiatzis et coll. 2004). C'est pourquoi l'entraînement en intervalle de haute intensité a été proposé pour cette population. Punzal et coll. (1991), proposait déjà il y a plusieurs années un entraînement à haute intensité, près du maximum et les auteurs ont pu observer que les patients MPOC modéré à sévère pouvaient effectuer ce type d'entraînement avec des symptômes limités et avoir de meilleure amélioration de leur capacité physique. D'ailleurs, plusieurs programmes utilisent la perception d'essoufflement afin d'ajuster l'intensité au lieu de la perception de l'effort pour les raisons présentées précédemment et semblent plus justes que l'utilisation de la fréquence cardiaque (Cooper 2001).

De plus, l'entraînement en force a pour principal but d'améliorer la fonction musculaire, due aux dysfonctions des muscles périphériques et de la faiblesse de ceux-ci chez les patients atteints de MPOC. Cet entraînement est recommandé surtout pour les patients ayant une faiblesse musculaire et permettrait d'augmenter leur masse musculaire en plus de leur force et leur endurance (Ortega 2002; Spruit et coll. 2002). Toutefois, le mode d'entraînement idéal reste inconnu (Gloeckl, Marinov, and Pitta 2013). Pour l'instant l'ATS recommande 2 à 4 séries de 12 répétitions à des intensités entre 50% et 80% d'une répétition maximale (1RM), 2 à 3 séances par semaine. Ce type d'entraînement demande à ce que le patient, généralement âgé, se familiarise avec ce mode d'exercice et de repos (Gloeckl, Marinov, and Pitta 2013). Possible contremesure grâce aux avancés technologique

Utilisation des jeux vidéo actifs, exergames, en réadaptation

La réadaptation à l'aide de jeux vidéo a déjà été explorée afin d'améliorer l'équilibre, la réadaptation de patron moteur, travailler la mémoire et le raisonnement spatial visuel avec différent type de population, dont des patients, en réadaptions post AVC, atteins de Parkinson, ainsi que des patients atteints d'une déficience visuelle (Lohse et coll. 2013). Ces technologies sont prometteuses par l'engagement (investissement du participant dans le jeu), la motivation et une facilité d'accès, c'est-à-dire pouvant être effectué autant à la maison qu'en centre de réadaptation sans nécessité de matériel supplémentaire au jeu et à la console, sont plus élevés chez les patients à condition que la structure du jeu soit appropriée (figure 1.9). C'est pourquoi Lohse et coll. (2013) ont émis des principes de structure de jeu essentiels à une réadaptation optimale par cette nouvelle technologie: la récompense, le défis/la difficulté, la rétroaction, le choix/l'interaction, des buts clairs/la mécanique de jeu et la socialisation. Ces principes de base déjà existants dans le monde du jeu vidéo (Dickey 2005) sont d'autant plus importants en réadaptation due aux enjeux reliés à la santé et pourraient avoir une répercussion importante sur la qualité de vie du patient.

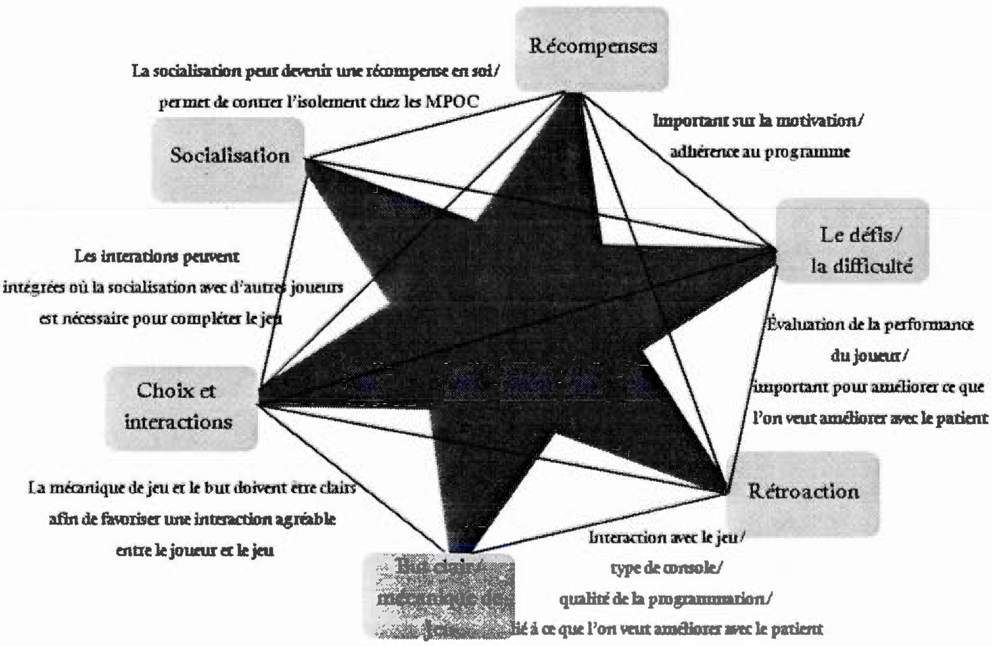

Figure 1. 9: Schéma des principes de mécaniques de jeux menant à l'engagement du joueur (tirée des principes soulevés par (Dickey 2005; Djaouti et coll. 2008; Lohse et coll. 2013))

La récompense

La récompense est une source de motivation non négligeable que ce soit pour un joueur ou pour une personne en réadaptation. Selon les principes de mécanique de jeux, il existe différentes méthodes de récompense telles qu'un titre ou un blason après l'achèvement d'une tâche ou la réalisation d'une quête menant à des items (King, Delfabbro et Griffiths 2010). D'après des études en neuroscience de la récompense et de la motivation, le système limbique, particulièrement le noyau accumbens est critique à l'apprentissage de nouveaux comportements, particulièrement ceux poursuivant des récompenses, le plaisir et la dépendance (Haber et Knutson 2009; Kalivas, Volkow, et Seamans 2005). Cela pourrait jouer favorablement à la rétention d'un programme d'activité physique/réadaptation à la maison (Biddiss and Irwin 2010). Ce paramètre est une clef importante pour le succès ou l'échec face à l'intérêt d'un jeu. Il faut par contre ajouter que ce paramètre reste extrêmement complexe et multifactoriel ne pouvant fournir une recette unique (Jakobsson et Sotamaa 2011)

Le défi/la difficulté

Ce principe est vrai autant en réadaptation que dans les jeux, le participant doit se familiariser, progressivement avec les tâches qui doivent devenir plus difficiles dans le temps (Lohse et coll. 2013). Un phénomène intéressant en lien avec cette progression où le joueur est excité et pressé de réessayer une tâche lorsque l'échec est positif. Cet échec positif se retrouve à être un échec où le joueur est très près de réussir suggérant une excitation à jouer et un plaisir plus grand que le succès par lui-même (Ravaja et coll. 2005). Sachant que la réadaptation d'un individu est ardue, démotivant et très souvent très long, ce type de modèle pourrait aider les patients à persévérer dans les exercices qui leur sont demandés, et ce, de manière ludique et excitante. Toutefois, il faut noter qu'en réadaptation les difficultés soulevées sont une interaction de l'individu et de ses contraintes environnementales pouvant être très diverses due à la blessure ou la maladie, sans parler de l'importance que les acquis par le jeu se doivent d'être transférable aux activités quotidiennes (Lohse et coll. 2013).

Rétroaction

La rétroaction est l'information remise au participant sur la performance reliée à la tâche. Cette information est primordiale en réadaptation, car elle permet de corriger/améliorer une ou des composantes qui ont été supprimées ou endommagées par la blessure ou la maladie (Broeren, Rydmark et Sunnerhagen 2004; Dingwell et Davis 1996). Ce type d'information permet d'améliorer des paramètres autant physiques, neurologiques que psychologiques/comportementaux, comme il est le cas dans certains jeux où la mécanique demande au joueur de coopérer pour pouvoir réussir (Lohse et coll. 2013). Lohse et coll. (2013) conseille également aux équipes de réadaptation de faire attention au type de rétroaction afin que ceux-ci soient positifs. Il a été observé en laboratoire (Chiviacowsky et Wulf 2007) que fournir des rétroactions positives, c'est-à-dire axé sur les essais réussis au lieu de ceux échoués favoriseraient la motivation à la pratique, le niveau de performance et la rétention (Hutchinsona et coll. 2008; Lewthwaite et Wulf 2010). Par contre, la qualité de la rétroaction est dépendante de la qualité de la programmation du jeu et le la sensibilité des appareils utilisés. Par exemple, les capteurs de mouvement ne sont pas tous aussi sensibles dans leur rétroaction du mouvement. Un capteur de mouvement tel la Wii (Nintendo, Jap), avec une manette ne permet pas d'analyser un mouvement dans son ensemble, l'analyse effectuée par la console est le mouvement d'une manette uniquement (Bidiss et Irwin 2010; O'Donovan et coll. 2012) Tandis qu'un détecteur de mouvement tel que la Kinect (Microsoft, USA) permet l'analyse du squelette humain dans les 3 axes, à la condition que la programmation soit assez "sensible" afin de détecter adéquatement les mouvements, surtout si ce sont des mouvements complexes ou en relation avec des objets. Cette limite de l'appareil doit être prise en compte par l'équipe médicale lors du choix du jeu ce qui n'est majoritairement pas fait dans de nombreuses études en réadaptation (Zerpa et coll. 2015).

Choix et interactions

L'interaction qui demande à faire des choix qui résultent en des conséquences différentes est une part intégrale du succès d'un jeu selon Lohse et coll. (2013). Ce paramètre évoque le désir ou non de rejouer à un jeu qui a déjà été complété. Ce construit actif, au contraire du passif comme être assis devant la télévision, permet une expérience de participation active cognitive et physique dans le jeu (Lohse et coll. 2013). Le concept de choix et de l'interaction augmentent l'engagement ainsi que la rétention (Chiviacowsky et Wulf 2005) pouvant ainsi influencer la rétention durant la réadaptation.

Buts clairs et mécaniques de jeux

Un but et les instructions claires permettent d'exécuter une tâche de manière efficiente. Au contraire le manque de but et d'instructions clair peut avoir un impact négatif sur la motivation du joueur. Dans le cas de la réadaptation, cela peut compromettre le bon rétablissement du patient. Des études précédentes ont observé qu'un patient motivé en réadaptation communiquait davantage avec l'équipe médicale et était plus rassuré sur l'atteinte des objectifs. Au contraire, un patient ayant des buts et informations nébuleux, celui-ci éprouvait de la confusion, de la frustration et ultimement une perte de motivation Lohse et coll. (2013).

Ce principe est un paramètre important de la motivation et de la rétention, il est en étroite relation avec le but, la rétroaction et les choix-interactions (Dickey 2007).

Socialisation

La socialisation et l'interaction sociale sont une des raisons primaires reportées par des joueurs en ligne . Cette opportunité de socialisation à distance et à proximité selon le jeu est bénéfique sur la motivation, l'engagement et l'apprentissage, car la coopération et la compétition avec un partenaire sont une source de rétroaction et d'encouragement. En plus de cette source motivationnelle, ce paramètre peut permettre de briser l'isolation pour plusieurs populations en réadaptation où les déplacements peuvent être extrêmement difficiles (Monsó et coll. 1998)

Ces principes sont essentiels au succès de la réadaptation par les jeux vidéo actifs. C'est pourquoi les études en réadaptation à l'aide de cette technologie ne prenant pas en considération ces éléments n'arrivent pas à des conclusions pouvant leur permettre de faire les choix de jeux adéquats en fonction de leur population. Parmi ces études, certains auteurs se sont penchés sur les jeux Wii pour une population atteinte de MPOC. Parmi ces études les principes de rétroaction n'ont pas été pris en considération et n'ont pas permis d'observer une amélioration à l'aide de cette technologie à des niveaux égaux à la réadaptation traditionnelle (LeGear et coll. 2016; Meinhardt et coll. 2013; Wardini et coll. 2013). De plus, le choix des jeux ne répondait pas aux recommandations de l'ATS pour l'intensité à atteindre et où le niveau et la structure d'un jeu sont similaires à la structure d'un entraînement et se doit d'être analysé à l'avance (Sell, Lillie, et Taylor 2010).

Les principes énumérés ci-dessus sont tout aussi pertinents lors de "gamification" de projet de promotion de l'activité physique, incluant l'utilisation de jeux vidéo actifs et d'applications mobiles. Certains risques physiologiques similaires à la MPOC sont reliés à l'inactivité telle qu'une diminution de la masse musculaire, la diminution de capacité cardiovasculaire, densité osseuse et à long terme pouvant influencer les capacités fonctionnelles reliées aux risques de dépression, isolement et une possible dégradation des facultés cognitives lors du vieillissement de l'individu (Rantanen et coll. 1999; Sesso et coll. 1998; Simonsick et coll. 1993). Les technologies de jeux vidéo actifs proposeraient une solution amusante et efficace de promouvoir l'exercice pour diminuer les risques reliés l'inactivité. Bidiss et Irwin (2010) ont d'ailleurs dénombré plusieurs articles observant que les jeux vidéo actifs ne pouvaient permettre d'atteindre des niveaux de dépenses énergétiques minimales pour rencontrer les normes en activité physiques (Garber et coll. 2011). Malheureusement, les paramètres de rétroaction et de mécaniques de jeux n'ont pas été pris en compte (Sell, Lillie, et Taylor 2010).

1.3. Question de recherche

Au regard des études antérieures et les besoins actuels exposés précédemment, est-ce que les technologies portables (wearable technology) peuvent mesurer les réponses physiologiques et aider à diminuer les impacts délétères des contraintes augmentées, ex., expédition en Antarctique ou chez des patients atteints de MPOC ?

Plus précisément, le présent projet de thèse s'est intéressé à observer les réponses physiologiques chez l'humain dans deux contextes de contraintes augmentées; soit une expédition en Antarctique en complète autonomie équipée des dernières technologies et méthodes d'exploration polaire et lors d'une première étude de faisabilité en centre hospitalier avant de tester un entraînement à la maison à l'aide de jeux vidéo actifs pour des personnes atteintes de MPOC. Ces études avaient pour but de valider quelles stratégies peuvent être proposées à l'aide des nouvelles technologies et comment celles-ci peuvent être améliorées/modifiées dans les deux contextes présentés.

CHAPITRE II: METHOLOGIE

2.1. Les participants

2.1.1. Méthodologie expédition en Antarctique (Chapitre 3 à 5)

L'étude a été approuvée par le comité d'éthique de l'Université du Québec à Montréal. L'expédition était composée de six membres (trois hommes et trois femmes, 25 ± 4 ans). Les membres étaient expérimentés dans les expéditions d'escalade et milieu polaires, à l'exception d'une personne (photographe) qui s'est ajoutée à l'équipe 3 mois avant l'expédition en Antarctique. L'équipe a participé à une mise en situation de 7 jours lors d'une pré-expédition logistique dans le champ de glace Columbia au Canada afin de préparer et vérifier les techniques, mettre à l'épreuve les capacités physiques et les défis psychologiques.

2.1.2. Différentiation de consoles de jeux vidéo afin de trouver l'appareil le plus efficace pour la réadaptation pulmonaire (chapitre 6)

Un total de 10 participants masculin, âgé de 26 ans (± 5) ans, jouant à des jeux vidéo régulièrement (22,5 ± 13,4 h / semaine) et engagé dans moins de 150 minutes d'activité physique par semaine ont été recrutés. Les critères de recrutement des joueurs avaient été fixés à un temps de jeu minimal de 5 heures / semaine selon Mentzoni et coll. (2011), où ils ont observé que la quantité moyenne hebdomadaire de temps de jeu pour les hommes âgés de 20-35 ans était de 5,5 ± 2,7 heures / semaine. Ce critère a été choisi en raison de l'absence d'une quantité précise de temps pour décrire un joueur. La plupart des études font plutôt un portait sur la psychopathologie du joueur et nécessitaient une analyse complexe sur l'obsession face aux jeux vidéo et la façon dont elle interfère avec la vie sociale, professionnelle et universitaire (Kuss and Griffiths 2012; Lafreinère et coll. 2009). Toutefois, il était important d'avoir des joueurs de jeux vidéo d'assez bon niveau dans le but qu'ils puissent comprendre rapidement les mécaniques de jeux (gameplay), étant donné qu'ils ne disposaient pas de pratique avant la session des jeux sélectionnés pour l'étude. Les critères d'exclusion étaient toute personne ayant une maladie cardiorespiratoire, lésions musculo-squelettiques ou d'autres restrictions d'activité physique. Tous les participants étaient non-fumeurs. La consommation de cigarette n'était pas dans les critères d'exclusion, par contre, le questionnaire distribué aux participants comprenant une question sur leur consommation des produits du tabac et cela s'est avéré qu'aucun d'entre eux n'en consommait. De plus, la participation était ouverte aux hommes comme aux femmes, mais aucune femme n'a répondu à l'appel de volontaire en dehors de l'équipe de recherche. L'approbation éthique pour cette étude a été obtenue auprès du Conseil de révision Institutionnel pour la recherche de l'Université du Québec à Montréal. Un consentement éclairé écrit a été obtenu chez tous les participants. Le Q-AAP (Questionnaire sur l'aptitude à l'activité physique), la fréquence cardiaque et la pression artérielle au repos ont également été complétés et mesurés avant d'effectuer les tests, respectivement. Selon la Société canadienne de physiologie de l'exercice (SCPE) cette mesure permet de vérifier la sécurité pour la participation à l'activité physique chez des personnes inactives (CSEP/ SCPE 2003).

2.1.3. Réponses physiologiques et faisabilité de l'utilisation d'un nouveau exergame à intervalles de haute intensité (chapitre 7 et 8)

Trente et un adultes sans restriction à l'activité physique (13 femmes et 18 hommes, âgés de 33 ± 4 ans) ayant un mode de vie inactif ou une faible pratique d'activité physique par semaine (<150 minutes d'activité physique par semaine) ont été recrutés pour participer à l'étude. Vingt et un d'entre eux (11 femmes et 10 hommes) ont été recrutés afin de s'entraînement à l'aide d'un jeu vidéo actif et dix (2 femmes et 8 hommes) pour participer à un entraînement traditionnel. Les participants ont été recrutés via des affiches et une invitation par les communications des activités sociales des employés dans une grande entreprise de jeux vidéo de Montréal. Étant donné qu'une clause de confidentialité était en place, dû au fait que le jeu ne faisait pas partie du domaine public durant le cours du projet, seuls des employés de l'entreprise pouvaient participer à l'étude. Les personnes touchées par une maladie cardiorespiratoire, lésion musculo-squelettique, ou autres restrictions pour l'activité physique ont été exclues du projet. L'approbation éthique pour cette étude a été obtenue du Comité d'éthique institutionnel de l'Université du Québec à Montréal. Les participants ont tous accepté de donner leur consentement écrit et signé. Le Q-AAP , la fréquence cardiaque et la pression artérielle au repos ont également été mesurés avant le début des tests afin d'assurer d'une participation sécuritaire pour les participants selon les normes de la SCPE (CSEP/ SCPE 2003). Deux femmes du groupe du jeu vidéo actif (9,5%) et un des hommes de l'entraînement traditionnel (10%) se sont retirés pour des raisons de temps, où ils ont manqué plus de 2 sessions. En outre, il a été plus difficile de recruter pour le groupe d'entraînement traditionnel que le groupe de jeux vidéo actif, ce qui explique l'échantillon plus restreint.

2.1.4. Faisabilité et réponses physiologiques d'un nouveau exergame à haute intensité en milieu clinique (chapitre 9)

Quatorze patients atteints de MPOC (8 hommes, âgés de 69 ± 6 ans et 6 femmes, âgées de 74 ± 6 ans) ont été recrutés à l'Hôtel-Dieu de Montréal. Les participants ont été recrutés par invitation verbale à la suite de leur séance habituelle de réadaptation pulmonaire. Les participants ayant une maladie cardiovasculaire primaire, blessure musculo-squelettique importante, histoire d'épilepsie ou d'autres restrictions à l'activité physique ont été exclus du projet. L'approbation éthique pour cette étude a été obtenue par le Comité d'éthique de la recherche avec des humains de l'Université du Québec de Montréal. Un formulaire de consentement écrit et signé a été obtenu de la part de tous les participants.

2.2. Situation de contraintes

2.2.1. Expédition en Antarctique (Chapitres 3 à 5)

Pré-expédition

En plus de la préparation via la pré-expédition, les participants ont tenu un journal quotidien de leurs activités de travail en tant que guides de tourisme d'aventure dans l'année précédant l'expédition en Antarctique. Le journal a été jumelé à la mesure de la charge de travail à l'aide des fréquences cardiaques et des distances parcourues durant leur travail (RS800, Polar, Fi), ainsi que les calories consommées. Le suivi et la communication avec le préparateur physique des participants étaient la plupart du temps par Internet (télé-entraînement). En plus de leur travail exigeant physiquement comme guides, des exercices spécifiques de type calisthenic (gymnastique suédoise) leur étaient prescrits pour augmenter la force et l'endurance nécessaire durant une expédition. Le volume de l'entraînement dispensé par les exercices a été déterminé par le volume d'activité physique au cours de leur travail comme guide.

Pour prédire les demandes physiologiques de l'effort musculaire durant l'expédition, c'est-à-dire, la dépense d'énergétique reliée à l'endurance et la force musculaire, une tâche simulée de cross-country en ski a été créée en laboratoire et extrapolée pour la durée de progression par jour, c'est-à-dire 12-15h par jour (~ 6-8 METS, 460-600 kcal / heure) pour chaque membre de l'expédition. La simulation a été réalisée à l'aide d'un tapis roulant non-motorisé (Hi-Trainer, Bromont, Qc, Canada) jumelé aux données.

d'études antérieures sur des expéditions polaires(Brotherhood et coll. 1986; Frykman et coll. 2003; A. Simpson 2010) . Brièvement, l'épreuve sur tapis roulant non-motorisé était progressive où l'effort pour déplacer la courroie durant la marche était augmenté chaque minute jusqu'à épuisement. Durant l'épreuve, chaque participant a eu à porter un analyseur métabolique portable (K4b2, Cosmed, It) afin de mesurer la consommation d'oxygène de pointe (VO_2peak). Le VO_2peak a été utilisé pour définir l'intensité des entraînements et pour le suivi au retour de l'expédition. De plus, afin d'être préparés au mieux, les participants ont été encouragés à prendre du poids (gras corporel et masse musculaire) pour le maintien des capacités physiques au cours de l'expédition.

Expédition

Les participants ont fait le trajet de Montréal à Ushuaia, en Argentine, par avion et où ils ont séjourné une semaine pour finaliser les préparations de l'équipage et de la cargaison avant la traversée du passage Drake en bateau (voir figure 2.1a). L'expédition en Antarctique était composée de la traversée à la voile du passage Drake qui représente une navigation d'environ 1700 km en mer dans l'un des passages les plus difficilement navigables sur la planète. Suite à la traversée, les membres de l'équipe d'exploration avaient à passer un mois d'expédition en Antarctique sur le Forbidden Plateau (voir figure 2.1b) en autonomie totale qui se termina par le retour à Ushuaia à travers le passage Drake à bord du même bateau à voile lors de la traversée initiale. Au débarquement au port d'Ushuaia, les participants sont demeurés une semaine dans la ville portuaire afin de finaliser les derniers préparatifs pour leur retour à Montréal.

Une grande partie de l'expédition s'est déroulée dans un isolement complet. Cependant, des téléphones satellites et une connexion satellite pour les médias sociaux étaient possibles et l'utilisation encouragée. Les participants ont progressé la plupart du temps en ski où la moitié des membres, en rotation, tirait environ 100 kg dans les traîneaux et chacun devait transporter un sac à dos afin de déplacer le matériel et la nourriture. Le temps moyen de progression quotidienne était de 10-15 heures avec une durée d'ensoleillement d'environ 12h.

La diète était composée de nourriture lyophilisée et de barres caloriques avec des additifs minéraux (Happy Yack et Xact nutrition, Montréal, Qc, Can) afin de permettre un apport nutritif par personne d'environ 5800 Kcal/jour (39 % de lipides, 46 % de glucides et de 14% protéines) pour les deux premières semaines et de 6500 Kcal/jour (43 % de lipides, 42 % de glucides et 15 % de protéines) pour les autres semaines. Ces quantités de nourriture ont été pré-emballées individuellement pour chaque repas, et l'équipe était informée de terminer tous les repas préparés. La même directive a été donnée pour les collations consommées pendant la journée. L'équipe était également informée qu'il devait boire 6L/jour/personne d'eau avec un petit ajout d'électrolytes. Dans le cas contraire, l'équipage était tenu d'aviser la responsable scientifique (spécialiste de mission sur place, dans le voilier encré à une journée de distance de l'équipe). Les conditions météorologiques étaient typiques pour les mois de février et mars, où les températures variaient entre -20 et -40 °C selon les rapports météo sur la bateau, de nombreux voiles blancs (whiteout) près du plateau et sur le plateau, accompagnés de vents atteignaient 100 km/h, où la visibilité était gravement réduite, composée également d'élévation de terrains et de crevasses ensevelies sous la neige. À l'aide des cartes en lignes il a été possible de cataloguer l'altitude du plus haut sommet escaladé environ 2200m et l'altitude moyenne du parcours sur le Forbidden plateau de 1400 m. ainsi qu'une distance parcourue de plus de 160 km.

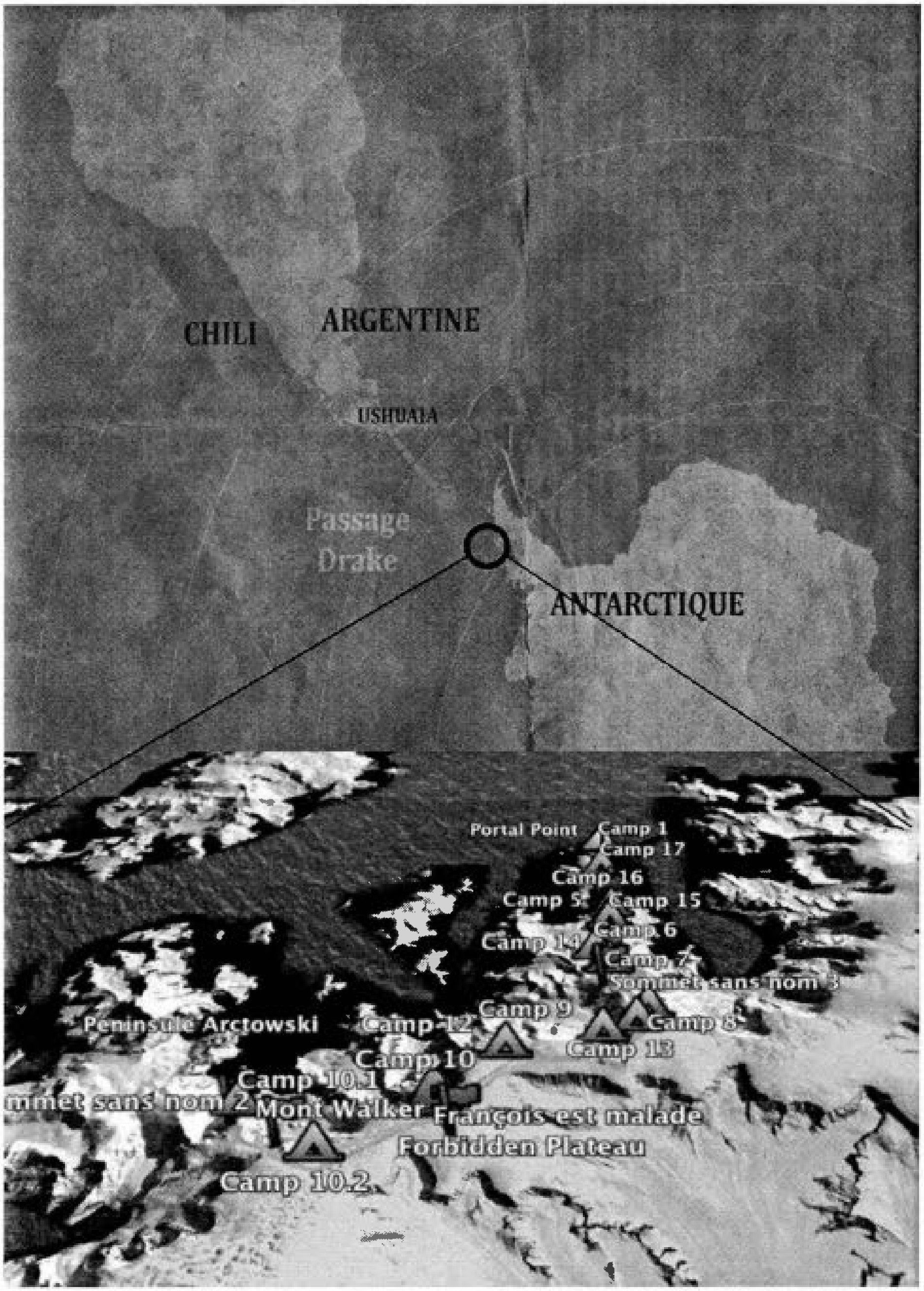

Figure 2. 1: a) Carte de l'expédition XP-Antarctique(tirée de présentations d'XP-Antarctik), b) Trajet de l'équipe en Antarctique tiré des images satellites (Image satellite provenant de Google Earth modifié par XP-Antarctik)

Les vêtements ont été choisis en fonction de la technologie la plus récente dans le milieu de l'expédition; l'isolation était assurée par plusieurs couches; une couche de base en laine mérinos, coton et autres textiles respirants à poids léger pour les couches du milieu couverts d'un coupe-vent (Mammoth, Gore-Tex, Seon, Switzerland). Lors des moments de repos ou lors des chutes de température, un manteau (Absolute Zero Parka, Mountain Hard Wear, CA, USA) était ajouté.Le poids pour les couches de pantalons (~0.8 kg), pour les couches de chandails et coupe-vent (~3kg) et aux pieds dont les bottes et bas (~1.9 kg) était d'environ 6kg. Les vêtements avaient comme objectif de maintenir le confort thermique en plein air, pendant l'activité de progression, tout en assurant une gestion de la sudation et d'un poids minimal. Les vêtements retirés dans la tente devaient être gardé à l'intérieur du sac de couchage pour assurer l'assèchement du textile et de les garder au chaud pendant la nuit. Le reste du matériel devait également correspondre à ces critères, garder l'équilibre thermique, assurer l'évaporation afin de garder l'équipement au sec pour un poids minimal composé d'une tente pour le camp de base (space station, Mountain Hard Wear, CA, USA) et d'une tente plus petite (Trango, Mountain Hard Wear, CA, USA) lors de l'escalade vers les sommets inexplorés. Les sacs de couchages utilisés étaient certifiés par le fabriquant à -34°C (Lamina Z Bonfire, Mountain Hard Wear, CA, USA).

2.2.2. Choix des consoles et jeux vidéo afin d'évaluer les jeux potentiels pour la réadaptation (Chapitre 6)

Les consoles choisies pour les jeux vidéo actifs ont été la Kinect (Xbox 360, Microsoft, USA) pour le système de capture du mouvement via une détection du mouvement du corps du participant et la Playstation Move (PlayStation3, Sony, Japon) (PS) pour le système capture du mouvement via une manette. La PS a été choisie plutôt que la Wii (Wii,Nintendo, Japon) pour le système de manette étant donné que les jeux sélectionnés étaient disponibles sur les deux consoles retenues, Kinect et PS, ce qui n'était pas possible avec la Wii. Les trois catégories de jeux sélectionnées étaient: la danse (JustDance 3), entraînement via un entraîneur embarqué dans le jeu vidéo, aussi appelé jeu d'entraînement (MiCoach,) et un "hack-and-slash", une forme particulière de jeu d'action caractérisée par un accent mis sur le combat (No More Heroes: Paradis des héros pour PS et Star Wars pour Kinect). Malheureusement, le jeu d'"hack-and-slash", ainsi que les autres jeux d'aventures n'étaient pas disponibles sur les deux consoles pour cette étude. Le choix de ces trois catégories correspond aux bases de l'élaboration de jeux vidéo et des mécaniques de jeux, où il est possible de retrouver ces 3 grandes catégories de jeux parmi les jeux vidéo actifs ("exergames").

Les jeux de PS ont été réalisées sous deux conditions: assise et debout. La raison d'observer ces 2 positions était que le système avec la manette est largement critiqué pour capter les mouvements du joueur où il est possible d'utiliser des astuces d'économie d'énergie (O'Donovan et coll. 2012). Cette technique permet de jouer assis en bougeant uniquement le poignet, une qualité où les joueurs habitués excellent. Il devenait donc intéressant de comparer ces deux types de conditions. De plus, l'avantage de la manette permettrait aux personnes en mobilité réduite d'utiliser ces jeux vidéo actifs, ce qui n'est pas possible avec le capteur de mouvement, car il doit reconnaître la totalité du corps (squelette) en position debout. En outre, le jeu d'entraînement, MiCoach, ne permettait pas de jouer en position assise en raison du petit détecteur mouvement par la camera qui est combiné à la détection du mouvement avec la manette, méthode spécifique seulement à ce jeu pour l'instant et à la PSMove. Ce ne qui n'est pas le cas pour les autres jeux où seul le mouvement de la manette est capté pour analyser le mouvement. C'est pour cette raison que seuls la danse et le jeu d'action ont été réalisés avec le système de contrôleur de PS pour une comparaison entre jouer en position assise vs debout.

Les niveaux de difficulté choisis dans les jeux ont été faits en fonction de la dépense énergétique qui n'est parfois pas prise en considération, ce qui explique des résultats contradictoires dans des études antérieures (Sell, Lillie, and Taylor 2010). C'est la raison pour laquelle le choix du niveau, le temps de jeu, compris entre 12-15min, et la progression dans les jeux ont été normalisés et décrits dans le paragraphe suivant.

Jeu de danse (JD). Le choix des danses dans Just Dance (JD) a été fait selon le système des points de sueur les plus élevés; ces points sont liés avec le tempo imposé par la danse. Un nombre de points de sueur supérieur identifie un rythme plus élevé et une dépense énergétique supérieure. Dans la présente étude, Party Rock Anthem, No Limit, Land of 1000 Dances ont été choisis, pour un total de 15 minutes de jeu avec un temps total de chargement entre les danses d'environ 3 minutes.

Jeu d'entraînement (MC): L'entraînement sélectionné dans MiCoach (MC) était: "condition physique générale" qui proposait à la fois un entraînement musculaire et cardiovasculaire, au mode débutant, étant donné que les participants avaient un mode de vie inactif. Cela représentait des exercices d'entraînement général d'environ 13 minutes de jeu actif.

Jeu d'action (SWK et NMHPS): Le jeu Star Wars Kinect (SWK) était dans le mode histoire (Jedi destin) du Chapitre 2: Providence où cette partie de chapitre demandait une exigence de combat accrue, les mouvements de combat étaient plus complexes, l'exigence était en action continue pour minimalement 12 minutes, et environ 15 minutes avec le temps de chargement. Il est à noter qu'une cinématique coupait le chapitre 2 en deux parties et offrait un temps de repos aux joueurs. Le jeu No More Heroes a été choisi pour PS (NMHPS) parce que la structure de jeu est basée sur une mécanique de "hack-and-slash", ce qui était rarement développé pour cette console au moment de la présente étude. Le niveau du jeu a été fixé à sucrer (facile) pour permettre aux participants de jouer pour minimalement 12 minutes consécutives et étant donné que la demande physique n'était pas plus grande aux autres niveaux.

Sessions de jeux vidéo

Le total de chaque session de jeu vidéo actif se retrouvait entre 12-15 minutes de jeu actif, c'est-à-dire, sans le temps de chargement du jeu, cinématique ou des explications. L'ordre des jeux était semi-aléatoire, où les jeux ont été placés dans un ordre différent, et ont été associés au hasard avec un participant. La dépense énergétique a été mesurée en utilisant un analyseur métabolique portable (K4b2, Cosmed, Italie) et la fréquence cardiaque à l'aide d'un cardiofréquencemètre (RS800, Polar, FI). Les données de consommation d'oxygène et de dépense énergétique ont été moyennées par incrément de 5 secondes. Après chaque session, les participants ont eu un minimum de 30 minutes de repos où ils pouvaient jouer à des jeux vidéo traditionnels sédentaires, c'est-à-dire en position assise sans exigence physique supérieure à bouger ses doigts sur un clavier ou une manette. La perception de l'effort (OMNI) a été prise à la fin de chaque session pour la perception de l'effort cardiorespiratoire et musculaire, individuellement.

Temps de repos

Pendant le temps de repos, les participants ont été autorisés à jouer à des jeux inactifs. Un moniteur de fréquence cardiaque permettait de mesurer la fréquence cardiaque pendant cette période et un brassard d'activité mesurant la dépense énergétique (Armband, BodyMedia Senswear, États-Unis) permettait de mesurer la dépense énergétique tout au long de l'étude.

2.2.3. Faisabilité de l'utilisation d'un nouveau exergame à intervalle de haute intensité (chapitre 7 et 8)

Procédures de l'entraînement du groupe jeux vidéo

La première séance d'entraînement par le jeu vidéo actif a permis de mesurer à l'aide d'un analyseur métabolique portable (K4b2, Cosmed, It) la dépense énergétique et les demandes cardiorespiratoires du jeu afin de construire les séances des semaines suivantes. Cette séance a également permis aux participants de se familiariser avec le jeu et la technique des exercices demandés.

Les participants ont joué un total de 60 à 80 minutes par semaine, avec une obligation d'un minimum de 60 minutes / semaine, mais avec la possibilité de poursuivre pour un total de 80 minutes sur deux sessions au cours d'une semaine pendant 6 semaines. Il est important de noter que les 60 minutes incluent le temps de chargement des jeux qui correspondait à un repos passif pour le joueur, le temps actif était d'environ 30 minutes. Il est à noter que les participants ont été autorisés à manquer un maximum de 2 sessions au cours du programme (pour un minimum de 5 semaines d'entraînement), au-dessus de ce nombre d'absences le participant était retiré de l'étude. Le nombre de répétitions de squat et pompes au cours du jeu a été comptabilisé. L'exercice devait être exécuté conformément à la standardisation SCEP (CSEP/ SCPE 2003). La perception de l'effort (OMNI) et de la perception de plaisir ont également été prises en note. Les FC des participants ont été mesurés à l'aide d'un cardiofréquencemètre (RS800, Polar, Fi) au cours de chaque session, celle-ci se situait entre 70-90% de la fréquence cardiaque maximale estimée à l'aide de la formule 220-âge ce qui correspondait à la planification suite aux tests préliminaires.

Un professionnel de l'activité physique était présent pour noter les résultats, assurer le suivi de l'entraînement, et assurer la sécurité des participants. En outre, le jeu était dans la phase pré-alpha et avait besoin de la présence d'un expert pour aider avec la navigation dans le jeu. Aucune blessure n'a été observée lors des entraînements.

L'entraînement traditionnel

Les participants s'entraînaient 3 séances par semaine, environ 1 heure par séance à la salle d'entraînement fournie par l'entreprise pendant 6 semaines afin d'atteindre les lignes directrices de l'ACSM, c'est-à-dire un minimum de 150 minutes / semaine d'activité physique modérée à vigoureuse (Garber et coll. 2011). Il est à noter que les participants ont été autorisés à manquer un maximum de 2 sessions au cours du programme, pour un minimum de 5 semaines d'entraînement comme pour le groupe jeux vidéo. L'entraînement était composé d'une session de course sur tapis roulant ou elliptique par intervalles, composé de 5 minutes d'échauffement, suivi par 7 à 8 intervalles d'effort d'une minute à 85-90% de la fréquence cardiaque maximale estimée et 30 secondes de repos actif (marche), et finalement un 5 minutes de retour au calme. Un entraînement musculaire suivait, composé d'un circuit de squats, de pompes sur appareil en position assise, du rameur et des redressements assis pour 3 séries de 12 répétitions. La session prenait fin avec des exercices de flexibilité. Le programme n'était pas supervisé par un entraîneur personnel, mais un entraîneur était disponible dans la salle de gym pour répondre aux questions ou aider les participants au cours de leur entraînement.

2.2.4. Test clinique d'un jeu vidéo actif avec des patients MPOC pour proposer un type d'entraînement à la maison (chapitre 9)

Procédures avec le jeu vidéo actif

Les participants ont été actifs pour un total de 30 minutes au cours d'une seule session de jeu (Shape-Up, Ubisoft Divertissement, Montréal) à l'aide d'une caméra de capture de mouvement (Kinect). La fréquence cardiaque, les paramètres respiratoires, la saturation et la consommation d'oxygène ont été recueillis à l'aide d'un analyseur métabolique portatif (MetaMax, Cortex, Allemagne). Le nombre de répétitions exécutées durant le jeu (punch, torsion du tronc, et levée de chaise) a été compté et noté. La perception d'effort ressenti aux jambes et de la perception d'essoufflement ont également été prises sur une échelle de Borg; une échelle entre 6 et 20, où 6 est sous très, très léger et 20 est un peu plus de très, très dur (O'Donnell et coll. 1995) . L'instruction principale pour les participants était de faire autant qu'ils pouvaient pendant le temps du mini- jeu. Un compte à rebours en haut de l'écran montrait le temps restant au cours du mini-jeu. Les instructions des mini-jeux constituant la session ont été données verbalement avec une courte démonstration par un membre de l'équipe de recherche et ont été modifiées pour la population de la MPOC. La session comprenait les mini-jeux suivant: un jeu de course (Stunt Run), un jeu de boxe (Arctic Punch), un jeu de torsion du tronc (To the Core), et un jeu de squats (Squat me to the Moon). Les mouvements demandés dans les mini-jeux ont été modifiés pour permettre aux participants de compléter les jeux autant que possible, ainsi être engagés et motivés par les mini-jeux malgré leurs limitations. Les participants étaient autorisés à se reposer sur une chaise placée derrière eux, et ce, à tout moment durant le jeu. Cependant, le temps continuait à s'écouler même si les participants décidaient de prendre un repos durant le mini-jeu.

Les exercices des mini-jeux sont détaillés dans les phrases suivantes. Les instructions du mini-jeu de course (Stunt Run) demandaient à élever les genoux aussi hauts que les participants étaient à l'aise de le faire et autant de fois qu'ils le pouvaient pendant le temps alloué au mini-jeu. Le mini-jeu montrait des obstacles, mais le participant était informé de les ignorer s'ils estimaient qu'ils étaient trop difficiles. Le mini-jeu de boxe (Arctic Punch) a été programmé pour suivre le rythme du participant. Les instructions étaient de donner un coup de poing sur le plus grand nombre de cibles qui s'activait aléatoirement. Les instructions pour le mini-jeu de torsion du tronc (To the Core) étaient de mettre les mains sur les hanches et tourner le tronc afin de naviguer dans le jeu. Enfin, le mini-jeu de squats (Squat me to the Moon) consistait à s'asseoir sur une chaise et se relever autant de fois que possible. Les mini-jeux duraient environ 1,5 min chacun, où entre les mini-jeux le participant prenait une pause assise sur une chaise afin de récupérer. Le masque de l'analyseur métabolique était retiré durant cette période. Les participants décidaient quand ils étaient prêts à continuer, ce qui pouvait durer environ 3-4 min, incluant les temps de chargement des mini-jeux. La fig. 2.2 explique les différents jeux et les demandes des exercices de ces mini-jeux.

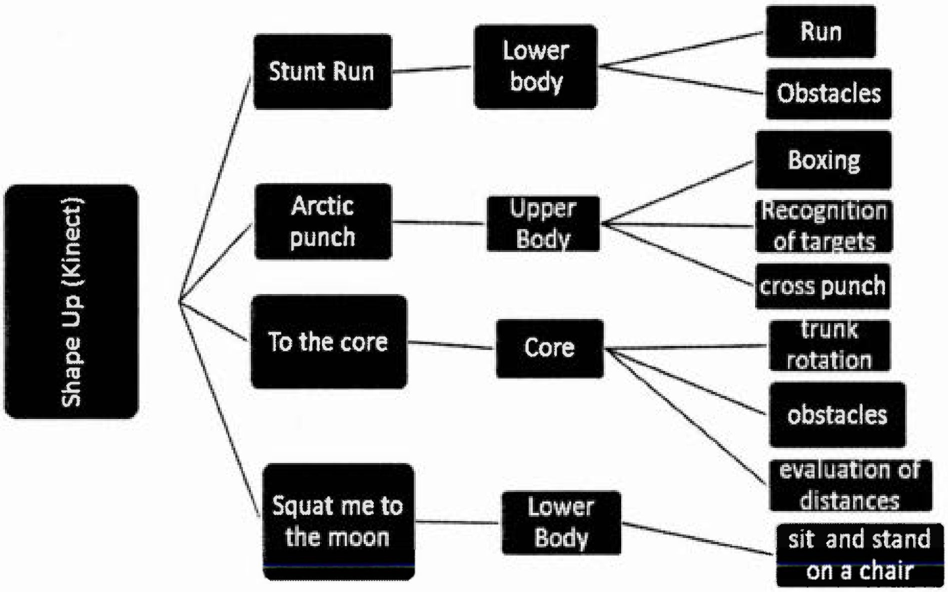

Figure 2. 2: Description des mini-jeux (chapitre 9)

2.3. Les évaluations pré-post

2.3.1. Évaluations pré-post expédition (chapitre 3 et 4)

Tests de condition physique pré-post ont été réalisée avant et après l'expédition Antarctique dans le Laboratoire de performance humaine à l'Université du Québec à Montréal .La figure 2.3 présente la ligne du temps des différentes mesures utilisées durant l'expédition.

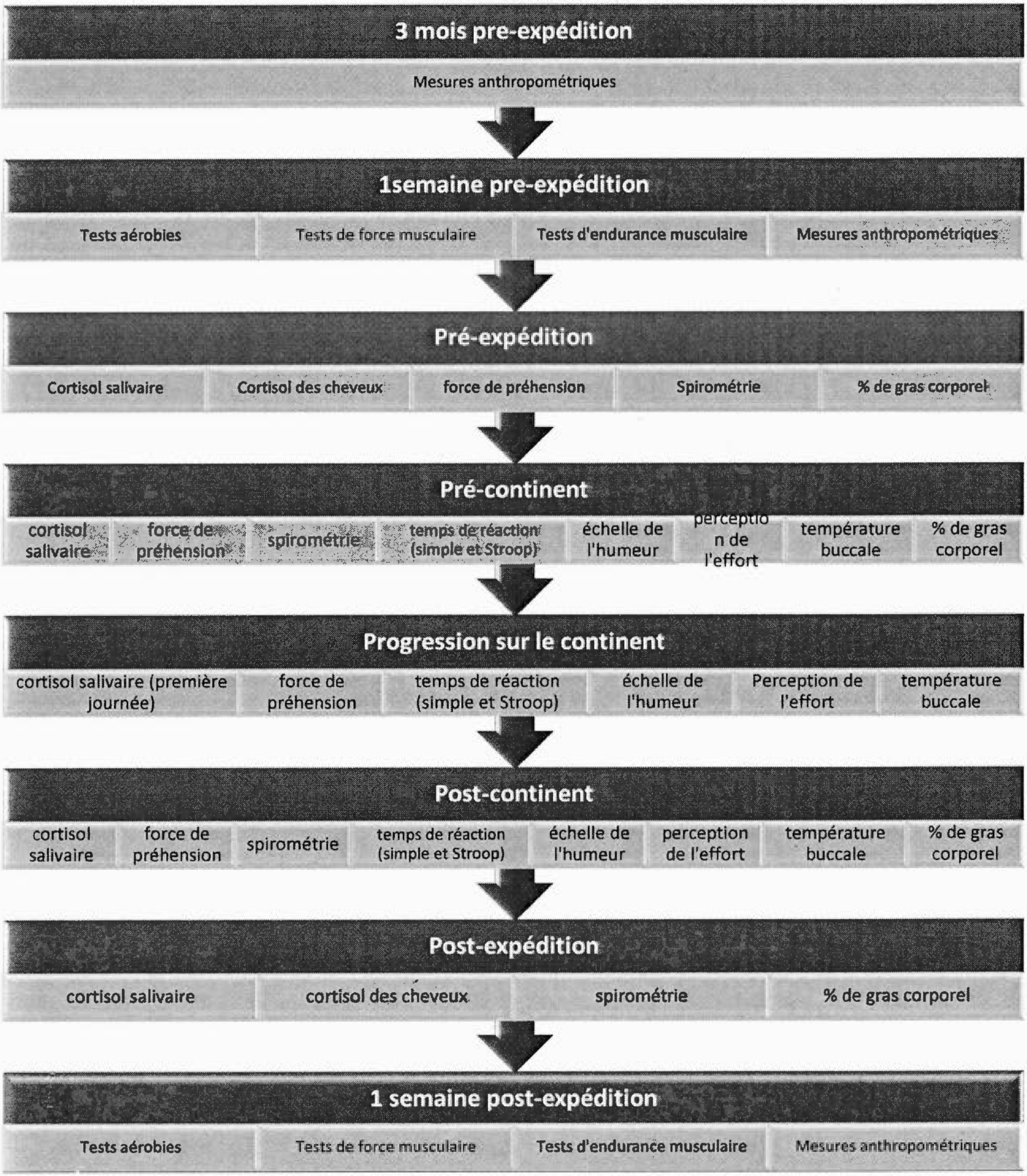

Figure 2. 3: Ligne du temps des procédures

Les mesures anthropométriques

Le pourcentage de gras corporel total a été mesuré par double absorptiométrie à rayons X (DEXA) (GE Prodigy Lunar , Orlando , États-Unis) comme établis par d'autres études antérieures (Sillanpää, Häkkinen, and Häkkinen 2013). Le poids a été mesuré à l'aide d'une balance électronique à 0,1kg près (BWB-800p, Tanita, Japon). Ces mesures ont été prises sur chaque participant trois fois :

1) au cours de la semaine avant la pré- expédition (trois mois avant l'expédition);

2) au cours de la semaine avant le vol vers l'Argentine pour prendre le bateau; et

3) la semaine après le retour de l'Argentine.

En outre, une autre mesure anthropométrique a été prise à l'aide d'un appareil à ultrasons portatif (Biometrix, Intrametrix,USA). L'ultrason a été utilisé pour mesurer le gras sous-cutané aux 7 sites de pli cutané de Jackson et Pollock (1985). Un % de gras corporel a été calculé par une équation adaptée basée sur l'équation de Jackson / Pollock 7-sites. L'évaluation a été effectuée avant d'embarquer sur le voilier, avant et après l'expédition sur le continent, lors de l'arrimage du voilier à Ushuaïa et à l'UQAM au retour de l'équipe à Montréal.

Tests musculaires:

Le protocole du test de la force de préhension consiste en une prise maximale d'une pince métallique, un dynamomètre (Lafayette dynamomètre à main, modèle 78010, In, USA). Le test a été effectué deux fois sur chaque main, le meilleur résultat de chaque main a été noté à ± 0,5 kg.

Le protocole du temps maximal de suspension à la barre haute consistait à maintenir une suspension du corps sur une barre haute pour une durée maximale tout en conservant une flexion au niveau du coude à un angle de 90 °. Le test terminait lorsque le participant était incapable de maintenir l'angle du coude après deux avertissements consécutifs ou une interruption volontaire de la part du participant en raison de l'épuisement. Le temps total en secondes a été noté.

Le protocole du temps maximal en position de la chaise au mur consistait à maintenir les genoux à un angle de 90 °ainsi qu'un angle de 90° au niveau des hanches. Le dos devait être appuyé contre le mur. Le test terminait lorsque le participant était incapable de maintenir l'angle de 90° aux différentes articulations après deux avertissements consécutifs ou une interruption volontaire par le participant en raison de l'épuisement. Le temps total en secondes était noté.

Le protocole de force consistait en un test de six répétitions maximales (6RM). Le participant tentait d'effectuer sept répétitions, dans la situation où elles sont réussies, le poids était augmenté pour la prochaine série. Un minimum de trois minutes de repos entre les tests devait être pris et un maximum de quatre séries a été effectué par jour. Le 6RM a été réalisé à l'aide l'appareil de presse assise et le tirage à la barre haute à l'aide une veste lestée. La presse assise a été réalisée unilatéralement, c'est-à-dire une jambe à la fois, afin d'avoir suffisamment de poids pour effectuer le test. Le 1RM a été extrapolé à l'aide du résultat au 6 RM et la table équivalence de l'ACSM (Heyward and Gibson 2014)

Test spécifique aérobie maximal (SMAT)

Le protocole de test spécifique aérobie consistait en une épreuve maximale de marche progressive sur un tapis roulant auto-propulsé (Hi-trainer, Bromont, Qc, Can). Le participant devait pousser la courroie du tapis roulant avec leurs pieds tout en reposant leurs hanches sur un support, ce qui simulait la cargaison chargée sur le traîneau qu'ils utiliseraient en Antarctique. La résistance du tapis roulant commençait à 10 lb pendant une minute suivie d'une période de repos de 15 secondes et augmentait de 10 lb chaque minute jusqu'à l'épuisement. Le participant devait maintenir une vitesse minimale de 1 m / s. Le test prenait fin lorsque les participants étaient épuisés ou incapables de maintenir la vitesse minimale. Les paramètres cardiorespiratoires de ventilation (VE), de la consommation d'oxygène (VO_2), et de la fréquence cardiaque (FC) ont été mesurés avec un analyseur portable métabolique (K4b2, Cosmed, It). La résistance maximale atteinte sur le tapis et la perception de l'effort (échelle de Borg) ont été notées.

Test de vitesse aérobie maximal (VAM)

Le protocole de test de vitesse aérobie maximal consistait en un test de course progressive maximale jusqu'à l'épuisement sur un tapis roulant motorisé (Quantum, LK). La vitesse initiale du tapis était fixée à 8km / h, avec 1% d'inclinaison pour une durée de trois minutes. Après l'échauffement, la vitesse de course était augmentée de 1 km / h chaque minute jusqu'à l'épuisement. Les paramètres cardiorespiratoires de VE, la VO_2, et la FC ont été mesurés avec un analyseur métabolique portable (K4b2, Cosmed, Il). La perception de l'effort et la vitesse maximale étaient notées.

Tests musculaires et test sous-maximal aérobie à température ambiante tempérée et température ambiante froide (TAST-F)

Les participants ont pris part à un test sous-maximal à température tempérée (20 ± 1 °C) et à température froide (-1 ± 8 °C). Les participants ont fait les tests à la température tempérée avant de débuter la période d'acclimatation à l'environnement froid durant environ 30 minutes, pour ensuite effectuer à nouveau les tests en exposition à la température froide. Les participants portaient les mêmes vêtements pour le test à température tempérée et à environnement froid, ainsi que pre- et post-l'expédition (environ 1 Clo). Les tests musculaires consistaient en un protocole de force de préhension et le test de temps maximal en suspension à la barre haute décrite précédemment, à l'exception que les participants utilisaient leur piolet appuyé à un cadre afin de simuler plus spécifiquement la tâche. Le test sous-maximal était composé d'un test d'escalier par paliers où le rythme de montée d'une marche était imposé et augmentait progressivement. Le tempo initial était de 18 pas / min pendant trois minutes avec 15 secondes de repos, suivi de deux autres étapes où le tempo a été augmenté à 24 et 30 pas / min. Les paramètres cardiorespiratoires (FC et VO_2) ont été mesurés avec un analyseur métabolique portable (K4b2, Cosmed, It). La température tympanique (Braun Thermoscan Pro 4000, NY, USA) a été mesurée après l'exercice. Notez que pour les mesures en environnement froid ont été prises à la température tempérée dans un court délai après l'exercice en raison de la température inférieure à 10 °C du au type de thermomètre n'arrive pas à lire adéquatement à de si basse température (selon le manufacturier). En outre, les températures prises ne sont pas représentatives de la température corporelle en raison de l'influence de la température froide qui influence la température dans l'oreille. Cependant, il donne une bonne estimation de la température de la peau à proximité de la tête et de la réponse de thermorégulation cérébrale.

Une extrapolation de la consommation maximale d'oxygène maximal a été calculée à l'aide de l'équation de régression linéaire de la relation entre la fréquence cardiaque et la consommation d'oxygène pour chaque palier. L'extrapolation a été effectuée avec la fréquence cardiaque maximale atteinte pendant la VAM. En outre, la comparaison entre la température ambiante et la température froide a été calculée en soustrayant la réponse en environnement tempéré à la réponse en environnement froid (Δctl-froid)

2.3.2. Tests durant l'expédition (chapitres 4 et 5)

La capacité vitale forcée et la force de préhension ont été mesurées avant l'embarquement, avant d'aller sur le continent, au retour du continent , et après l'arrimage du voilier à Ushuaia. La capacité vitale forcée a été mesurée selon les normes de l' ATS (Wanger et coll. 2005) avec un spiromètre portable (SpiroThor , wavefront manipulé spiromètre , Thor , Budapest , Hongrie) et la force de préhension a été mesurée selon les normes de la SCPE (SCPE 2003) avec un dynamomètre (dynamomètre Lafayette , Lafayette Instrument Company, Indiana , USA).

La température orale a été prise selon les normes d'études antérieures(Livingstone et coll. 1983; Moran and Mendal 2002), les participants devaient prendre leur température dans la tente le matin, sans sortir préalablement et sans prise de liquide ou d'aliment 30 min précédentes la prise de mesure. La température orale a été mesurée à l'aide d'un thermomètre numérique (Digital Pro, Physiologie, San Diego, Californie, USA). La température a été notée chaque semaine.

Le temps de réaction simple, le test de Stroop, l'OMNI-échelle de perception de l'effort, et l'échelle de la perception de l'humeur (PANAS) ont été mesurée chaque semaine, cependant, l'équipe a oublié de prendre la mesure à la fin de la deuxième semaine. Le temps de réaction simple à l'aide d'une application maison. Le test de

Stroop a été effectué à l'aide d'application sur une tablette (ToughPad FZ-G1, Panasonic, Kadoma, Osaka Japon). Les tâches étaient les suivantes: appuyer sur l'écran le plus rapidement possible après l'apparition d'un carré noir, la moyenne et le meilleur temps pour exécuter la tâche pour 10 essais de temps de réaction simple ont été notés. La deuxième tâche était un test de Stroop (application maison) où le participant devait appuyer l'écriture le plus rapidement possible sur la couleur correspondant à l'écriture des mots apparaissant où les mots apparaissant étaient des noms de couleurs différentes de la couleur de l'écriture. L'échelle OMNI est une perception de l'effort validé(Robertson et coll. 2003; Utter et coll. 2004) de 0 à 10, où 0 est extrêmement facile et 10 est extrêmement difficile. L'échelle de l'humeur a été mesurée à l'aide de la version française du PANAS (Gaudreau, Sanchez, and Blondin 2006; Watson, Clark, and Tellegen 1988), où la question posée était: "Au cours de la dernière semaine, pouvez-vous décrire ce que vous avez ressenti?" L'échelle contient 20 émotions notées sur une échelle de type Likert à 5 points ("pas du tout ou très légèrement" à "extrêmement"). Les émotions positives et négatives sont analysées pour évaluer le niveau de chacun. Le cortisol salivaire et le cortisol des cheveux ont été pris selon les normes d'études antérieures (Stalder and Kirschbaum 2012). La salive a été recueillie dans un tube à essai Salivette (Sarsted, Romelsdorf, Allemagne) en humectant un tampon et non en mâchant qui a été pris avant l'embarquement sur le voilier, avant d'aller sur le continent, le retour du continent sur le voilier, et après l'arrimage du voilier à Ushaïa. La prise de salive s'effectuait selon le protocole décrit par (Gröschl et coll. 2001) ; à la même heure, 6h00 le matin au réveil, sans avoir consommé de breuvage, nourriture ou médication, ni effectué d'exercice physique ou brossé les dents 6 heures précédant la prise. Les échantillons ont été préservés dans un congélateur sur le voilier et ont été analysés au retour à Montréal où les échantillons ont été conservés dans un congélateur à -80°C. Les cheveux ont été prélevés au-dessus du trou occipital avant l'expédition afin d'analyser le mois précédent l'expédition, un autre échantillon a été pris après l'expédition afin de mesurer le cortisol durant l'expédition selon les normes et le questionnaire de l'étude de Meyer et Novak (2012) et Stalder et Kirschbaum (2012). Le cortisol salivaire est présenté en% d'écart de la valeur de référence prévue pour chaque participant en fonction de leur âge, le sexe et le moment de la journée (Aardal and Holm 1995).

L'analyse du cortisol salivaire a été effectuée au retour à l'aide d'un ensemble d'analyse ELISA (EIA essay, Arbor Assays,MI, USA) par Department of Psychiatry and Department of Anatomy & Cell Biology au Douglas Mental Health University Institute. Toutefois, les valeurs de bases, dues à un problème technique, c'était dégradé lors de l'analyse. C'est pourquoi les valeurs de bases retenues proviennent de l'étude de Aardal and Holm 1995 en fonction de l'âge, du sexe et du moment de la journée. Les échantillons de cheveux ont été analysés à l'aide d'un ensemble d'analyse ELISA par le Centre d'étude sur le stress humain à Montréal, Canada.

La fréquence cardiaque, la fréquence respiratoire et la température cutanée étaient mesurées durant l'expédition à l'aide d'une chemise intelligente (Astroskin, Agence Spatiale canadienne). Les données étaient téléchargées et envoyées sur une tablette et envoyées via satellite à l'équipe médicale. Les batteries de l'appareil étaient rechargées à toutes les 24h, permettant de mesurer, une journée sur deux, quatre explorateurs sur les six portaient ce type de chemise. Toutefois, il est à noter qu'une chemise s'est brisée au début de l'expédition ne permettant de suivre que 3 explorateurs.

2.3.3. Évaluation de la condition physique des joueurs (chapitres 6)

Des mesures anthropométriques ont été prises au début de l'étude. Ces mesures consistaient à prendre: la grandeur, le poids et le pourcentage de gras corporel par bioimpédance (Tanita, Arlington Heights, Illinois). L'indice de masse corporelle (IMC) a été calculé par la suite. Un test d'escalier sous-maximal à une marche a été réalisé. Le test avait trois niveaux de rythme imposé pré-enregistrés à 18, 24 et 30 pas / min respectivement, de trois minutes chacun. Les participants devaient synchroniser leurs pas avec le tempo imposé, où le mouvement de montée et descente de la marche a été distribué en quatre temps. La fréquence cardiaque a été mesurée et notée à la fin de chaque étape. L'équation de l'ACSM pour un test d'escalier afin d'estimer la VO_2 (ACSM 2010) a été utilisée pour extrapoler la VO_2max des participants. La fréquence cardiaque a été mesurée à l'aide d'un cardiofréquencemètre (RS800 , Polar , Fi) . La perception de l'effort a également été prise à la fin à l'aide de l'échelle OMNI. Un retour au calme de cinq minutes après le test aérobie sous-maximal a été enregistré.

2.3.4. Procédures d'évaluation de la condition physique des participants inactifs pour le projet du jeu à haute intensité (chapitre 7 et 8)

Tous les participants ont été informés sur les procédures et les exercices, où un membre de l'équipe de recherche a fait la démonstration de tous les exercices au début de chaque test. Le mouvement était corrigé si le participant n'exécutait pas l'exercice correctement. Un essai d'une répétition était prévu au début de chaque test afin de s'assurer de la compréhension du test par le participant. L'évaluation de la condition physique a été effectuée au début et à la fin de l'étude.

Les mesures anthropométriques

Les mesures anthropométriques incluaient: la grandeur (le plus proche de 0,5 cm), le poids (0,1 kg), les circonférences de la taille, les hanches et les fesses, le % de gras corporel et % de masse maigre par ultrasons (bodymetrix, Intralametrix, États-Unis) au niveau des 7 sites de Jackson et Pollock (Jackson and Pollock 1985). L'équation permettant de calculer le % de gras corporel et de masse maigre prenait en considération le sexe du participant et le niveau d'activité physique des participants, c'est à dire inactif.

Test de la capacité aérobie

Le test aérobie sous-maximal était un test progressif d'escalier. Le test était constitué de trois paliers où le rythme imposé pour exécuter la tâche de monter la marche était de 18, 24 et 30 pas / min, de trois minutes chaque palier. L'action de monter et descendre la marche était décomposée en 4 phases correspondant chacun à un battement, incluant un timbre sonore différent pour la phase de montée et la phase de descente. La fréquence cardiaque était mesurée à la fin de chaque palier. L'équation de l'ACSM (ACSM 2010) a été utilisée pour extrapoler la VO_2max du participant. La fréquence cardiaque a été mesurée à l'aide d'un cardiofréquencemètre (RS800, Polar, Fi) et la perception de l'effort par une échelle de Borg modifiée, prise également à la fin de chaque palier. La fréquence cardiaque devait être inférieure à 100 battements / minute avant que le participant puisse continuer à la prochaine épreuve.

Les deux tests musculaires ci-dessous correspondent à la structure du jeu vidéo actif afin de pouvoir comparer l'aspect motivationnel d'un test physique en gymnase vs. dans un jeu vidéo. Les participants n'étaient pas avertis de ce stratagème.

Tests d'endurance musculaire

Le test de squat était composé de trois séries de 25, 20 et 15 secondes de squats avec un repos de 15 secondes entre chaque série. Les instructions données aux participants étaient de faire un maximum de répétition de squats possible au cours des trois séries. Le membre de l'équipe de recherche informait les participants du temps de fin et de départ des séries. Les participants étaient informés dès le début de l'épreuve que si le squat ne correspondait pas aux exigences, c'est-à-dire s'accroupir jusqu'à ce que les genoux soit à 90 degrés, le poids corporel sur les talons et un dos droit, la répétition ne comptait pas. Le total de répétition était noté. La fréquence cardiaque devait être inférieure à 100 battements / minute avant que le participant puisse continuer à la prochaine épreuve.

Le test de pompes était constitué de cinq séries de 15 secondes chacune, avec cinq secondes de repos entre chaque série. Les instructions données aux participants étaient de faire un maximum de répétitions de pompes pendant cinq séries de 15 secondes. Pendant le repos de cinq minutes, ils pouvaient rester en position de planche ou rester sur le sol, dans l'optique de conserver les mêmes conditions que dans le jeu. Le participant était informé dès le début du test que la pompe devait être conforme aux lignes directrices de la SCPE (CSEP/ SCPE 2003), sinon la répétition ne pouvait être comptée. Les femmes devaient faire les pompes sur leurs genoux et des hommes sur la pointe des pieds. La fréquence cardiaque devait être inférieure à 100 battements / minute avant que le participant puisse continuer à la prochaine épreuve.

Test de flexibilité

Un test de flexion du tronc modifiée mesurée avec un flexomètre (Flex-Tester, Novel produit, IL, USA) a permis de mesurer la flexibilité de la chaîne postérieure des participants. Le protocole était conforme à l'évaluation de la SCPE (CSEP/ SCPE 2003)

2.3.5. Évaluation des patients MPOC pour l'étude clinique avec un jeu vidéo actif (chapitre 9)

Toutes les évaluations des patients MPOC ont été effectuées par l'équipe médicale de l'Hôtel-Dieu lors de l'évaluation de routine des patients. Les données ont été remises à l'équipe de recherche à la suite d'un consentement écrit de la part des patients.

2.4. Analyse statistique

2.4.1. Expédition (Chapitre 3 à 5)

En raison de la taille de l'échantillon, un test Shapiro -Wilk a été utilisée pour déterminer si la distribution était normale (Razali and Wah 2011). Les effets de l'expédition (pré vs post) sur la condition physique ont été analysés à l'aide du test nonparametrique pour 2 échantillons liés pour les données qui n'étaient pas normalement distribués (Wilcoxon) et par un test-T apparié pour les données normalement distribuées. Une différence significative à été érigée au niveau p = 0,05. Les résultats ont été rapportés en moyenne ± écart-type. L'analyse statistique a été effectuée en utilisant SPSS 20 (IBM, USA).

2.4.2. Type de consoles et de jeux vidéo actif (Chapitre 6)

Les résultats ont été présentés sous la forme de moyenne ± écart type . Un test-t apparié et ANOVA à mesure répétée avec une correction de Bonferroni ont été utilisés pour évaluer les différences possibles de la dépense énergétique (calories et METS) et les réponses cardiovasculaires (VO_2, FC) des différents jeux et consoles (p <0,05). Les données ont été analysées à l'aide de SPSS 20 (IBM).

2.4.3. .L'analyse des données du jeu vidéo actif à intervalle de haute intensité (Chapitre 7 et 8)

Les données ont été analysées à l'aide du logiciel SPSS 21. Les résultats ont été présentés en format moyenne ± écart type. Un test-T apparié fut utilisé pour comparer les mesures pré vs post et une analyse ANOVA mesures répétées a été utilisés pour calculer les différences entre les groupes et le sexe.

2.4.4. Analyse des données de l'étude clinique avec les patients MPOC (chapitre 9)

Les résultats ont été présentés sous forme de moyenne ± écart type. Une ANOVA à mesures répétées a été effectuée afin d'observer s'il existait des différences significatives dans l'intensité des différents jeux.

CHAPITRE III: ACCLIMATATION APRES 30 JOURS D'EXPEDITION EN ANTARCTIQUE

3.1. Mise en contexte

L'Antarctique est un milieu imposant plusieurs contraintes aux explorateurs s'aventurant dans ce milieu. Les réponses physiologiques dans ce milieu peuvent avoir des conséquences délétères sur la condition physique, mais aussi mener à certaines acclimatations face à ce milieu. Le présent chapitre tente d'observer ces changements physiologiques à la suite d'une expédition d'un mois en Antarctique. Parmi l'observation de ces changements, il sera possible d'observer pour une première fois l'impact du sexe dans les expéditions polaires en complète autonomie où les femmes n'étaient habituellement pas dans les études antérieures. Ces observations offrent un premier regard, néanmoins, restreint sur un échantillon de 3 femmes où des études plus avancées devront être poursuivies.

3.2. Résumé

L'Antarctique n'est pas un habitat naturel pour l'être humain. Un groupe de six explorateurs (trois femmes et trois hommes) ont participé à une expédition en Antarctique. L'objectif était d'observer l'acclimatation physiologique des explorateurs en utilisant les stratégies suivantes: préparation physique pre-expédition par télé-entraînement, un apport nutritionnel riche en calories (majoritairement lipide et glucide) et en utilisant de l'équipement technologique moderne. Des mesures anthropométriques (DXA), des tests aérobies spécifiques maximaux, des tests de vitesse maximale aérobie, des tests aérobies sous-maximaux, des tests de résistance (force de préhension, presse assise sur la jambe et tirage à la barre haute), et des tests d'endurance (temps maximal de suspension à la barre haute et de la position de la chaise) ont été réalisés avant et après l'expédition. En raison de la taille de l'échantillon, un test t apparié a été utilisé pour des données distribuées normalement et le test de Wilcoxon pour les autres valeurs afin de comparer avant et après expédition. La masse maigre pour les femmes était significativement plus élevée après l'expédition (45.4±4.4 vs. 47.1±4.1 kg; $p=0.040$, $d=1.86$),.

Cependant, aucune différence significative n'a été observée pour les hommes (66.7±7.3 vs. 66.0±5.7kg; (p=0.180, *d*=0.11). Les améliorations pré-post-expédition étaient significatif pour le test aérobie maximal spécifique, où la VO_2 de pointe était 40.8±4.2 VS 46.9±7.4 ml/kg/min, de pré-post respectivement, (p=0.027, *d*=1.01), mais aucune différence significative n'a été observée pour les autres tests aérobies. Les tests musculaires n'ont pas permis d'observer une différence marquée pré-post expédition, excepté pour la jambe gauche pour l'extrapolation d'une répétition maximale (295 ± 110lb VS 364±135 lb, pré-post respectivement, p = 0,031, d = -0,56). Les stratégies utilisées pour l'expédition semblent être un aspect clé d'une expédition en Antarctique, afin de contrecarrer les effets délétères sur la capacité physique. Cependant, d'autres études devront être développées pour observer l'importance de chaque composante et stratégie de préparation individuellement.

3.3. Article

3.3.1. Titre: XP-Antarctik expedition: the Effect of a Month long Expedition in Antarctica on Physiological Performance

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3.3.2. *Abstract*

Antarctica is a challenging habitat for humans. A group of 6 explorers (3 women and 3 men) participated in an expedition in Antarctica. The objective was to observe the physiological acclimatization of the explorers using the following strategies: physical preparation, high-caloric nutritional intake and, the latest physiological monitoring equipment. Anthropometric measures (DXA), specific maximal aerobic test, maximal aerobic running speed test, submaximal aerobic cold testing, strength tests (grip strength, leg press and chin up), and endurance tests (bar suspension and chair position) were conducted pre-post expedition. Due to the sample size, a paired t-test was used for normally distributed data and non-parametric (Wilcoxon) to compare values pre- and post-expedition. Effect size are presented as Cohen's *d*. The lean mass for the women was significantly higher after the expedition (45.4±4.4 vs. 47.1±4.1 kg; $p=0.040$, $d=1.86$), however, no significant difference was observed for the men (66.7±7.3 vs. 66.0±5.7kg; ($p=0.180$, $d=0.11$). Pre-post-expedition values were significantly different for the specific maximal aerobic test, where the VO_2peak was 40.8±4.2 VS 46.9±7.4 ml/kg/min, respectively ($p=0.027$, $d=1.01$), but no significant difference was observed for the other aerobic test. The muscular testing didn't change significantly, except for the left leg 1 Maximal Repetition (295±110 vs. 364±135 lb, pre-post respectively, $p=0.031$, $d=-0.56$). The overall physical fitness preparation for the expedition appears to be a key aspect in order to countermeasure the physical ability decay during an Antarctica expedition. However, further studies will need to be developed to differentiate the importance of the preparation components.

Key words: Antarctica expedition, fitness, physiological acclimatization

3.3.3. Introduction

Explorers venturing to Antarctica are exposed to one of the most physically demanding environments on Earth, and despite modern technology, Antarctica is still extremely hostile to humans (Acheson et al. 1980; Bishop, Grobler, and Schjoii 2001; Frykman et al. 2003). Antarctica holds the world's record for the coldest temperature that was registered at Vostok, - 89.6°C, as well as the continent that is the windiest, highest, and driest (Kennedy 1993; Simpson 2010; Stocks et al. 2004). Fortunately, today's Antarctic expeditions are managed differently from historic expeditions like Captain Robert Scott, whom 100 years ago led a team of explorers to the south pole (Halsey and Stroud 2012). In fact, to the best of our knowledge, only a few studies have reported the physiological consequences of prolonged sledge pulling ski trek expeditions without external support (complete autonomy) in Polar environments (Bishop, Grobler, & Schjoii, 2001; Frykman et al., 2003 Halsey & Stroud, 2012; Halsey et al., 2016; Stroud, Coward, & Sawyer, 1993). Nonetheless, past scientific research expeditions have contributed to expand our present understanding of Antarctica and the human physiological responses to this environment, even so, there is still much to discover on human adaptation/acclimatisation (Halsey and Stroud 2012; Simpson 2010).

<u>*Physical fitness performance and polar expeditions*</u>

Physical fitness performances after Antarctic residences or expeditions are controversial and depend on activity patterns and the time and conditions of exposure (Simpson 2010). Positive adaptation has been shown by Budd (1965) where physical fitness improvement occurred after six weeks of outdoor work at cold exposure. It is not known, however, if it was attributed to cold exposure or work intensity. Nonetheless, similar results were observed for one man (in a crew of 2 men) during a ski-trek and sledge pulling expedition (Frykman et al. 2003). The majority of these studies, however, were conducted on men with small sample sizes (ex., 1 or 2 subjects). Furthermore, these studies indicated that pulling a sledge required high energy demands, particularly for physically smaller men that typically expend energy faster that can have a be detrimental effect on skeletal muscle performance (Halsey and Stroud 2012). In fact muscle performance deterioration has been reported to be caused by energy store depletion. This physiological deterioration of muscle performance has also been linked, as reported in a previous study, to fluid retention by the body in response to malnutrition, perhaps brought about by the underestimation of the energy expenditure due to the cold, the sledge pulling, the sleep deprivation, and the altitude (Halsey and Stroud 2012). As well, skeletal muscle physiological performance decreases when exposed to cold, even for a single short exposure time (Stocks, Taylor, Tipton, Greenleaf, et al. 2004). Cold exposure decreases maximal strength, muscular endurance, cardiovascular performance, and significantly increases the metabolic cost of physical activities (Mäkinen 2007; Oksa et al. 2004; Stocks et al. 2004). Hence, despite the possibility for muscle performance deterioration, it also seems plausible that long term cold exposure is not entirely deleterious to physical fitness as long as the initial preparation, the caloric intake, the acclimatization, or the level of physical activity during the expedition, meet the required demands. Nonetheless, exposure to cold is one of the factors in polar expeditions that influence physical performance and still needs to be understand better to help explorers in future expeditions.

Physiological responses to cold exposure

Cardiorespiratory responses and performance at cold

It is still not well established how the cold affects certain physiological responses, such as, for example, the oxygen uptake at maximal (VO_2max) or at submaximal exercise. Some studies observe no changes in the VO_2max (Sandsund et al. 1998), while other studies report decreases as a function of the temperature (Oksa et al. 2004; Patton and Vogel 1984; Quirion et al. 1989). Moreover, at submaximal exercise, some studies observe higher oxygen uptake requirements at cold temperatures (Kruk et al. 1990; Oksa et al. 2004; Sandsund et al. 1998; Therminarias 1992), while other investigators report no significant difference (Jacobs, Romet, & Kerrigan-Brown, 1985; Patton & Vogel, 1984). Thus, correct knowledge of oxygen consumption (VO_2) in a cold environment is important, such as in a sledge pulling ski trek polar expedition, so that nutritional rations estimates can meet the energy expenditure and prevent or at the very least, decrease the impact of body weight loss that may lead to a deterioration in physical performance.

Power, strength during expedition in Antarctica

Several investigators have observed that human body cooling causes a decrement in maximal muscle force, shortening velocity, and an increase the time to reach maximal force (Bergh & Ekblom 1979; Davis & Young 1983). In fact, the impaired power and force production of cooled muscles may be due to changes in their neuromuscular function that can decrease performance and further increase injury risks (Mäkinen 2007). Furthermore, at dynamic exercise, the muscular performance decreases, especially during fast contraction velocities (Oksa et al. 2004). This decrement in muscle contraction with cooling has been explained by Oksa et al (1995) by a slowing of the agonist muscle function shown by a decrease in EMG-activity accompanied by an increase in EMG-activity in the antagonist muscle group. Thus this power and strength decline at cold can have an impact on the performance during an expedition where the load during the ski-pulling trek can be important.

Adaptation/acclimatization to cold environment

Repeated cold exposure leads to physiological changes, but there are still controversies surrounding the precise nature of adaptation/acclimatization to the cold environments (Cheung 2015; Makinen 2010). However, studies agree that thermal sensations and sensation of pain decrease with time and repeated exposure to cold temperatures (Barwood, Corbett, and Wagstaff 2014; Geurts, Sleivert, and Cheung 2006; Mekjavic, Dobnikar, and Kounalakis 2013). At the same time, this thermal sensation and pain decreasing induces a greater risk of cold injuries, such as frost bites (Leppäluoto, Korhonen, and Hassi 2001; Makinen 2010). Despite this risk, according to Launay and Savourey (2009), cold adaptations represent one of the means of prevention of pathophysiology effects of exposure to cold temperatures. The authors explain that adaptation to cold induces less discomfort, preserves dexterity, prevents general and local cold illnesses and injuries, and improves surviving in a cold environment. However, many previous studies did not differentiate between acclimation, acclimatization, adaptation, and habituation. (Launay and Savourey 2009) describe the term *adaptation* as the changes that reduce the physiologic strain produced by the cold, unlike the term *acclimation* where the changes are in response to an experimentally and specific condition (e.g. wind or temperature) or the term *acclimatization* where the changes occur as a response to a natural climate, as it is the case in the present study. The last term defined by Launay and Savourey (2009) was the term *habituation* used to elicit new physiological responses or more pronounced physiological reactions induced by an acclimatization or acclimation. Thus, the mechanisms that occur under conditions of acclimatization and habituation can help the physiological preparation of polar explorers before an expedition.

Present strategies during expedition in Antarctica

Based on our current knowledge, strategies are proposed in order to succeed surviving in the Antarctic environment including; the ingestion of a high calorie diet, favoring fats and carbohydrates over proteins to reduce wasting and degradation in performance (Halsey and Stroud 2012). This is based on a hypothesis for marathon running (Tsintzas et al. 1995) that is still controversial, mostly because of the impossibility for some people to absorb high-fat diets (Stroud 1998). Moreover, modern endurance rations include micronutrients in abundance, something that was not present during the heroic age of Antarctic exploration (Halsey and Stroud 2012). Another strategy is physical training before an expedition where, for example, during a sledge-pulling expedition the adventurers must haul sufficient food to survive the journey, and thus, must physically prepare adequately as athletes would do for their specific sport. Thus, present-day explorers aim to begin their journeys with a heightened body mass in order to counter the high energy expenditure during the expedition, even though this can perhaps prove difficult since they have to bear the extra-weight. Finally, due technological advancements, clothes and equipment are lighter and more efficient to protect against the cold, the wind, and the humidity (Halsey and Stroud 2012). Nevertheless, in spite of all available new information, technological advancements, and strategies, modern explorers remain uncertain about optimal dietary rations and optimal fitness preparation. Further research on these strategies is critical knowing that Antarctica tourism and adventures in extreme environments are growing in popularity. Finally, the majority of research reported in Antarctica was mostly on men and outcomes on women are needed (Simpson and Maynard 2012). Thus, the aim of the current study was to investigate the effects of a month expedition in Antarctica on a mixed gender crew of six explorers, to observe changes in physical fitness while being sustained on a high fat diet, latest technologies in equipment, and fitness preparation strategies. Specifically, measurements before and after (pre and post) the expedition were taken to assess acclimatization to a cold environment on: 1) maximal and submaximal aerobic fitness and; 2) muscular endurance and strength fitness. The hypothesis was that adventurers would have no or minimal decrease in their fitness after the expedition due to the balanced energy intake and energy expenditure that was maintained with a high-fat diet, efficient low weight equipment and proper physical preparation to support the expedition load.

3.3.4. Methodology

A part of the following methodology was reported in another paper (Parent and al. in submission). The present paper focuses on measurements taken before and after the expedition (pre-post, respectively), as illustrated in Figure 3.1.

Participants

The study was approved by the University of Quebec in Montreal ethics committee. The crew was composed of 6 members (3 men and 3 women, 25 ± 4 years old where the range was 23 to 30 years old). All members had experience in expeditions (3 adventure tourism guides, an experienced climber, and an ex-military man) except one, the photographer that was added to the team 3 months prior to the expedition. The entire crew participated in a 7-day acclimatization and logistical pre-expedition in the Columbia ice field to prepare and review team techniques, and the physical and psychological challenges.

Procedure

Preparation

In addition to the pre-expedition preparation, participants kept a daily diary of their work activities, most of them as adventure tourism guides, in the year leading up to the Antarctica expedition. The diary was used to keep track of the distance covered during the adventure tourism, calories consumed, and heart rate (monitored with heart rate monitor, RS800, Polar, Fi). On top of their physically demanding work as tourism guides, specific callisthenic exercises (exercises to be achieved with the body weight that do not require equipment) were sent to the crew to increase individual strength and endurance that is required to do their work. The training volume provided by the callisthenic exercises was determined as a function of the physical demand required by their individual work prior to the expedition. Furthermore, participants were encouraged to gain weight (fat and muscle) for physical sustainment during the expedition.

Expedition

The participants performed the tests in Canada before stay one week at Ushuaïa, Argentina, to finalize the crew and cargo manifests. The Antarctic expedition was composed of sailing across the Drake pass (~1700 km sea travel), followed by a 30-day expedition in Antarctica on the Forbidden Plateau completing an entirely autonomous ski-trekking, sledge pulling progression, and finished by returning to Ushua¸ïa by sail across the Drake pass. The participants remaining in Ushaïa one week before returning to Canada. The conditions on the Forbidden Plateau was for most of the expedition spent in complete isolation, however, satellite phone and wireless (satellite) connection to social media was available. The participants progressed, most of the time on skis, each pulling approximately 100 kg equipment-laden sleds and backpacks. The average daily progress time was 10-15 hours with a daily sunshine duration of 12 hours. The food intake was freeze-dried food and caloric bars with mineral additives (Happy Yack and Xact nutrition, Montreal, Qc, Can) totaling around 5800 calories per person per day for the 2 first weeks and 6500 calories per person per day for the other weeks. This amount of calories was set in individual packages for every meal and the team was instructed to finish all the meals prepared. The same instruction was given to snacks during the day and the water in the morning provided by melting snow (6L per person per day). If one or more of the crew member was not able to finish the prepared food package, the crew was required to inform the scientist in charge. There were frequent "whiteouts" where visibility and contrast are severely reduced by snow, terrain elevation, and undetectable troughs, with temperatures around -20 to -40 °C recorded with the ship weather report. The altitude peak reached was around 2200m, the plateau altitude was around 1400 m and the distance traveled more than 160 km according to open source satellite pictures. The clothing was last technology used in an expedition; the thermal insulation was provided by several layers with light and efficient technologies (Mammoth, Gore-Tex, Switzerland, Icebreaker, Merino, Canada and Mountain Hard Wear, USA) .

Assessments Pre- and Post-Expedition

Fitness testing was performed before and after the Antarctica expedition in the Human Performance Laboratory at the University of Quebec in Montreal.

Anthropometric Measurements

Total body fat was measured by dual x-ray absorptiometry (DXA, GE Prodigy Lunar, USA) as established by others (Sillanpää, Häkkinen, and Häkkinen 2013). The measurements were taken on each participant three times; during the week before the pre-expedition (three months before the expedition), during the week before the flight to Argentina to take the boat, and the week after the return from Argentina.

Muscular Fitness Tests:

The grip strength test protocol consisted of exerting a maximal grip on a dynamometer (Lafayette hand dynamometer, model 78010, USA). The test was performed twice on each hand. The best result from each hand was noted at ±0.5 kg and summed.

The hang maximal suspension time (bar suspension) protocol (SMT) consisted of maintaining a flexion at the elbow at an angle of 90° where the body was in suspension for a maximum time without support. The test finished when the participant was unable to sustain the elbow angle after two consecutive warnings or if the participant voluntary stop himself due to exhaustion. The total time in seconds was noted.

The chair position for a maximal time protocol (CMT) consisted of maintaining knees at an angle of 90° whilst leaning back against the wall. The test finished when the participant was unable to maintain the knee angle after two consecutive warnings or voluntary termination by the participant due to exhaustion. The total time in seconds was noted.

The strength test protocol consisted of six maximal repetitions (6MR). The participant tried to perform six repetition, where a seven repetition was not possible to do. In the situation where they succeeded to perform seven repetitions, the weight was increased for the next set. A minimum of three minutes rest was taken between the sets and a maximum of four sets were performed per day. The 6MR was performed using the leg press and the chin up exercise with a weighted jacket. The leg press was performed per leg in order to have enough weight to perform the test. The 1RM was extrapolated to the 6RM measurement with the ACSM equivalent table(Heyward and Gibson 2014).

Specific Maximal Aerobic Test (SMAT)

The specific aerobic test protocol consisted of a maximal progressive walk test on a self-propelled treadmill (Hi-trainer, Bromont, Can). The participant had to push the treadmill belt with their feet while resting their hips on a support that simulated the cargo laden-sled. The treadmill resistance began at 10lb for one minute followed by a 15 sec rest period, it increased 10lb every minute until exhaustion. The participant needed to maintain a minimum speed of 1m/s. The test was terminated when participants were exhausted or unable to maintain the minimum speed. The gas collection, cardiorespiratory parameters (ventilation (VE), oxygen uptake (VO_2), and heart rate (HR)) were measured with a portable metabolic analyzer (K4b2, Cosmed, It), and the maximal treadmill resistance and the effort perception (Borg scale) was noted.

Maximal Aerobic running speed Test (MARS)

The maximal aerobic test protocol consisted of a maximal progressive running test to exhaustion on a motorized treadmill (Quantum, LK). The initial treadmill running speed was set at 8km/h with 1% inclination for a three minute warm-up. Following the warm-up, every minute, running speed was increased by 1 km/h until exhaustion. The gas collection, cardiorespiratory parameters (ventilation, V_E), oxygen uptake (VO_2), and heart rate (HR)) were measured with a portable metabolic analyzer (K4b2, Cosmed, It), and the maximal speed and effort perception was noted

Muscular tests and aerobic sub-maximal test at control (CTL) and cold environmental temperatures (ASMT)

Participants took part in a sub-maximal test at controlled ambient temperature (20 ± 1°C) and at a cold temperature (-1 ± 8°C). The participants did the tests at the ambient controlled temperature before acclimatization to the cold temperature environment for approximately 30 minutes and performing the tests again. The participants kept the same amount of clothing for both controlled temperature and cold environment tests and for the tests before and after the expedition (approximately 1 Clo). The tests consisted of a grip strength protocol and the maximal suspension time described before.

The sub-maximal test consisted of a single step step-test at a tempo of two beats to step up and two beats to step back down to the initial start position. The initial tempo was 18 steps/min for three minutes with 15 sec of rest, followed by two further stages where the tempo was increased to 24 and 30 steps/min. The same clothes were worn during the tests at the controlled ambient and cold temperatures. Gas collection and cardiorespiratory parameters (HR and VO2) were measured with a portable metabolic analyzer (K4b2, Cosmed, It). The tympanic temperature (Braun Thermoscan Pro 4000, NY, USA) was measured after the exercise. Notice that for the cold environment measurement, we asked the participants to quickly take the temperature due to the cold temperature. Furthermore, the temperatures taken are not the body/core temperatures because of the influence of cold temperature that may influence the temperature in the ear. However, it gives a good estimate of the skin temperature close to the head and cerebral thermoregulation response (Mariak et al. 1994). An extrapolation of the maximal oxygen uptake was calculated by the linear regression equation from the relation between heart rate and oxygen uptake for every participant and extrapolated to the maximal heart rate reached during the MARS. Furthermore, the comparison between control temperature and cold temperature was calculated by subtracting the control response to cold response (Δ ctl-cold).

Statistical Analysis

Due to the sample size, a Shapiro-Wilk was used to test the normal distribution (Razali and Wah 2011). The effect of the expedition (pre- vs. post-) on fitness was analyzed using the nonparametric test for two related samples for the data that was not normally distributed and paired t-test for the data normally distributed. Significance was set at the p=0.05 level. Effect size (ES) was calculated and presented using Cohen's *d*. The following scale was used for the ES interpretation (*d*): small effect size: 0.2; moderate effect size: 0.5; large effect size: 0.8; very large effect size: 1.3 (Sullivan and Feinn 2012). Results are reported as mean ± standard deviation. The statistical analysis was performed using SPSS Statistic 20 (IBM, USA).

3.3.5. Results

Anthropometric measures.

The participant's anthropometric measures are presented in Table 3.1. The % of body fat was significantly lower after the expeditionnoted that one of the explorers was sick during the expedition and did not eat the recommended diet. Furthermore, the women lean mass increased significantly after the expedition. However, the weight, the BMI and lean mass for the entire group and the men group did not change significantly. Nonetheless, during the preparation for the expedition, the men significantly increased their weight (79.8±4.0kg vs. 79.8±3.9kg, Z=, p=, pre- vs. post-expedition respectively) (figure 3.2 A).

Strength and muscular endurance.

Strength and muscular endurance measurements are presented in table 3.2. The pre- vs. post-measurements indicated no significant difference except for the RM extrapolated left leg test. Cardiorespiratory fitness.

Cardiorespiratory fitness measurements are presented in Table 3.2. The SMAT test significantly increase the VO_2peak after the expedition. Furthermore, theVO_2peak, the %VO_2 at ventilation threshold (VT) increase for both maximal cardiorespiratory test. The MARS test was also a significant decrease of VEpeak post-expedition. However, no significant difference was observe for the other parameters. (

Response to the cold

The muscular tests and aerobic sub-maximal tests at control and cold environmental temperatures measurements are presented in Table 3.3 and the ΔCTL-cold environment are presented at figure 3.2 B, C, D and E. The VO_2 during the stage 2 and 3 (last stage) and the HR at the end of the stage 2 was significantly lower post-expedition

ΔCTL-cold pre vs post expedition

The difference between CTL and the cold environment (ΔCTL-cold) was significantly higher after the expedition for the grip strength ((p=0,058 (*d*=0.91) and the VO_2 at the stage 2 (p=0.007 (*d*=1.39)). Furthermore, the VO_2 at the last stage had a strong ES (p=0.058 (*d* =1.23)), respectively). However, the other parameters ΔCTL-cold was not significant different pre-post expedition (figure 3.2).

CTL vs cold environment

Pre-expedition, the HR at stage 1 and 3 was significantly lower at cold environment (p=0.036, (*d*=0.53) and p=0.054 (*d*=1.20), respectively) and the tympanic temperature was significantly lower at cold environment (p=0.027, (*d*=3.25)). However, the other parameters was not significantly different between the CTL and cold environment pre-expedition. Nonetheless, after the expedition, the grip strength (p=0.024, (*d*=0.44)), the HR for all the 3 stage (HR stage 1, p=0.039,(*d*=0.67); HR stage 2, p=0.025,(*d*=0.71); and HR stage 3, p=0.001, (*d*=0.99)), the VO_2 at stage 2, 3 and extrapolated (p=0.042, (*d*=1.29); p=0.011,(*d*=1.39); and p=0.053,(*d*=0.91) (respectively) and the tympanic temperature (p=0.028, *d*=2.03) was significantly lower at cold, but no significant difference was observed for the other parameters

3.3.6. Discussion

The main finding of this study was that the fitness capacity was preserved, and even marginally improved as shown by the SMAT test results and the maximal strength leg press test with the left leg, perhaps due to the ability to maintain muscle mass. Furthermore, knowing that previous expeditions (Halsey and Stroud 2012; Stroud 2001) had important lean mass loss, a surprising result was to observe a significant improvement of the lean mass for the women group. Moreover, this study observed acclimatization to a cold environment where the VO_2 during submaximal aerobic exercises at cold environment after the expedition decreased significantly without observing a significant difference in the VO_2 at the ambient (control) temperature. Something, that to the best of our knowledge, that has never been reported after an expedition in a cold environment.

Maintenance of the lean body mass

During the expedition, weight loss was minimized, possibly due to an adequate high-calorie diet. More interestingly, the lean mass was maintained, and for the women it increased, promoting an improvement in physical fitness. Similar finding was observed in a previous studiy, where a few ski-trekkers slightly increased lean mass (Frykman et al. 2003), however other ski-trekkers decreased their lean mass after a similar and even in the same expedition (Frykman et al. 2003; Halsey and Stroud 2012; Helge et al. 2003; Paulin et al. 2015)). Furthermore, a previous study explain that a sledge pulling expedition induce vigorous physical activity, promoting gains in the lean mass if the energy deficit is minor (Frykman et al. 2003). However, the lean mass improvement in these studies was minor and not significant. In the present study, the loss of total percent body mass pre VS. post expedition was significantly lower after the expedition, but the effect size was small, perhaps indicating that the energy deficit was minor, where the lean mass can show a gain and corroborate the previous studies statement. Furthermore, the minor energy deficit was similar to Frykman et al's. study (2003), where the authors explain that the low %body fat decreasing and remaining in the healthy %fat range, the participants maintained or gained lean mass, allowing a fitness capacity improvement. Furthermore, with some of the studies that observed decreasing fitness and lean mass, the diet was inadequate; the energy intake was insufficient to compensate for the energy expenditure of the expedition (Stroud 1998; Stroud 2001).

Fitness improvement

Muscle strength and endurance

The maintenance, and improvement, of the muscular strength and endurance indicated the possibility of maintaining physical capabilities by the absence of deleterious physical effects. Previous studies showed controversial results about muscle endurance and strength after sled pulling in polar expeditions. Frykman et al (2003) showed that the two explorers reacted inversely, where one improved his strength the other one decreased, and it was the inverse for the endurance. Stroud (2001) observed a strength loss after the expedition, however the participant was in a negative energy balance. The present study does not show a significant decline in endurance or strength, surprisingly an improvement in the leg press for the left leg, possibly due to using this leg to initiate the first step of pulling sledge or when they had to wait in a slope. According to Stocks et al. (2004), high levels of physical endurance work can influence cold resistance. Previous studies reported an improvement in cold tolerance and elevation of thermoregulatory sensitivity with endurance-trained subjects (Bittel et al. 1988; Kollias, Boileau, and Buskirk 1972). However, this thermoregulation efficiency can be disturbed by exercise-induced fatigue, sleep deprivation, and food restriction and this can induced a lower cold tolerance due to reducing tissue insulation (fat loss) (Young et al. 1998). The present expedition seems to be able to gauge the amount of exercise intensity during the progression, the dedicated time to sleep, and the calorie intake amount to keep this thermoregulation efficiency in order to maintain and improve muscular capacity.

Aerobic capacity

Aerobic capacity assessment showed no impairment to the cardiorespiratory fitness after the expedition even if the participants performed high-intensity exercise during the expedition in a severe cold environment. Moreover, the SMAT shows a significantly increased VO_2peak after the expedition. However, it is also possible that improvement was mostly due to the improvement of the lean mass due to when the VO_2peak is presented in relation to the lean mass, no significant difference was observed pre-post expedition, but a large effect size can be observed for the specific aerobic maximal test. Moreover, the VE peak reached at exhaustion was significantly lower after the expedition with the MARS. This measure can indicate an improvement in the cardiorespiratory function in the way that at the similar VO_2peak (no significant difference pre- vs. post-) the participants needed to ventilate less. Something not observed with the SMAT, maybe due to a higher VO_2peak reached. Another useful index for aerobic endurance sports like triathlon and cycling is the ventilation threshold (VT) (Bentley and McNaughton 2003) and this can distinguish performance when expressed in relation to $\%VO_2$max (Loftin and Warren 1994). The ability to sustain high intensity exercise during an endurance exercise appears to be related to the VT relative to $\%VO_2$peak (Amann et al. 2004; Roels et al. 2005). The VT increased significantly for the SMAT test showing an improvement in the cardiorespiratory function in addition to the improvement of the VO_2peak reach. Moreover, previous studies suggest a physiological change due to high-volume endurance workloads during a polar expedition transforming muscle to favor type 1, slow-twitch, and observed type 2, fast-twitch, muscles to degrade (Frykman et al. 2003; Schantz, Henriksson, and Jansson 1983), showing a reduction in anaerobic capacity, and improvement in aerobic capacity. This change can favor the improvement of the maximal aerobic tests, as observed in the present study. However, previous studies do not corroborate this improvement in the aerobic capacity (Helge et al. 2003; Stroud 2001), where the VO_2max decreases after the expedition. The previous studies used treadmill running progressive tests where only the VO_2max was analyzed. This no-specific test showed even in our study that it can be difficult to observe improvement due to the kind of task during an expedition. The present study suggests that it is possible to maintain and improve aerobic capacity, but the choice of the test is important and has to be specific to observe an improvement like observed with assessment of athletes (Girard et al. 2006). Moreover, the higher lean mass can explain a part of this improvement.

Acclimatization to cold environment

Submaximal-aerobic test

Acclimatization to cold environments seems to show an improvement during the submaximal-aerobic test. The improvement can be observed by the metabolic cost (VO_2) during the second and last stage of the test; for the same intensity level the crew needed to consume significantly less energy after the expedition, and this even if at control temperature, no significant difference was observed. Furthermore, the ΔCTL and cold temperature for the VO_2 at stage 2 significantly different pre-post expedition, and a strong ES was observed for the VO_2 at last stage. Previous studies are somewhat contradictory about the oxygen uptake at submaximal exercise intensity in cold environment. Oksa et al. (2004) observed the VO_2 increasing at cold compared to CTL temperatures at a different range of intensities during progressive exercise. This observation was corroborate at a low exercise intensity (Kruk et al. 1990) at a cold environmental temperatures between -15°C to 9°C. However, other studies did not observe a significant difference between the VO_2 at submaximal exercise intensity for temperatures between 20 and -20°C (Jacobs, Romet, and Kerrigan-Brown 1985; Patton and Vogel 1984)This last studies corroborating our measurements before the expedition, but not after a prolonged exposition to cold (post-expedition). Oksa et al. (2004) explain this contradiction by different levels of exercise intensity and a different temperature range. The authors observe that the VO_2 increases significantly at cold environment when the exercise intensity was set at 25% VO_2max for a temperature range of -15° C vs. 20°C . Furthermore, the VO_2 increased significantly higher at cold when a exercise intensity set at 50% VO2max for a temperature range is between 0°C vs. -15°C, compare to an exercise at 25%VO_2max for the same temperature range. Stocks et al. (2004) goes further by suggesting that for a submaximal exercise at cold environment the metabolic cost increases proportionally with the work rate, but inversely with the temperature , i.e. that the VO_2 will increase with the intensity level, but will also increase when the temperature decreases (colder environment). The present study did not this statement where the VO_2 was not significantly different between CTL and cold environment before the expedition. Furthermore, after the expedition the VO_2 at stage 2 (around 50%VO_2peak), at stage 3 (around 57% VO_2peak) and the extrapolated VO_2 max at cold at submaximal exercise was lower than the same intensity at CTL environment.. This inverse result can possibly explain by the clothing, where Oksa et al. (2004) increase the number of clo, and weight from the clothing for colder temperature. The present study used the same clothing for the CTL and cold temperature and for pre-post expedition. Furthermore, no indication was explained for a time at rest in the cold environment before the submaximal exercise. Moreover, there can be multiple mechanisms causing the contradictory results about oxygen uptake at cold environment. Three hypotheses was proposed by Oska et al. 2004 to explain the lower results in VO_2peak as: the amount of circulating blood may be less at cold environment, the possibility of cooling-induced neuromuscular changes where the muscle contraction and/or nerves are slower, and a bronchus constriction induced by the cold environment which decreases the amount of air ventilated and possibly a more severe constriction at colder temperature. Some hypotheses were proposed for the inverse effect (higher oxygen uptake at cold environment) by(Jacobs, Romet, and Kerrigan-Brown 1985; Timmons, Araujo, and Thomas 1985), as increasing thermoregulatory tonus of the muscles, co-activation altering neuromuscular function, and additional clothing, where in the present study the amount of clothes was the same between controlled and cold environmental temperature. However, after a long prolonged time at cold, the ΔCTL-cold VO_2 was significantly lower , possibly due to a cold acclimatization where the neuromuscular and thermoregulation at cold can be more effective and allow a lower cost energy for the same exercise intensity without be explain by a fitness improvement. However this hypothesis needs more investigation. It was also possible to observe a significant difference for the HR between control temperature and cold environment response at submaximal exercise. The heart rate response at cold environment during rest and exercise are lower than control temperature in previous studies (Oksa et al. 2004; Therminarias 1992), which corroborate our data. Finally, the cardiorespiratory response after a long exposition to cold need more investigation for a a better caloric intake estimation in polar expedition. The food composition is calculated based on energy expenditure during the expedition where the weight of food plays also an important place in the energy expenditure.

Tympanic temperature

Furthermore, the tympanic temperature ΔCTL-cold temperature exposure after exercise was not significantly different. The tympanic temperature to measure body temperature is generally accepted for ambient controlled environment, but can be influenced by cold environment (Livingstone et al. 1983). Moreover, for this study, the tympanic temperature was mainly used to measure cold acclimatization of the head thermoregulation, mostly because the head of participants was exposed to cold temperature without head protection during the test (hat, helmet...). Even if Brinnel and Cabanac (1989) showed that tympanic taken precisely in the anterior, inferior quarter of the tympanic membrane were unaffected by skin temperature, it remains that the infrared thermometer can be affected at a temperature lower than 10°C . However, this tympanic measurement was used to measure temperature changes in the head, more precisely the ears and cerebral thermoregulation (Mariak et al. 1994). This non-invasive and easily accessible measure give an estimation about changes in the internal carotid artery, which supplies the hypothalamus, brain region where the temperature is regulated (Lim, Byrne, and Lee 2008) and the cerebrospinal fluid between the perilymphatic spaces in the internal ear that could play a role in heat transfer (Mariak et al., 1994). These indicators provide information on the head thermoregulation acclimatization to cold environment, however, no significant difference was observed pre-post expedition.

The muscular tests at cold environment seem to maintain and even trend to decrease the performance after the expedition. In the present study, the grip strength ΔCTL-cold pre- vs. post-expedition was significantly higher, where the grip strength value at cold was not significantly different pre-post expedition, but with an effect size moderate. This trend corroborates previous studies about decreasing grip strength at cold environment after long-term cold exposure (Cheung 2015; Heus, Daanen, and Havenith 1995). However, the grip strength p value reported alone corroborate other previous studies; observed no significant difference for the grip strength performance after long-term or repeated exposing to cold temperatures in workers (Cheung et al. 2003). It was reported in Cheung et al. (2003) study that some protection mechanisms can be involved by repeated cold exposures, mostly for hand exposures. The vasoconstrictions and neurotransmitters can be involved to protect the core temperature, explaining, in part, the results of the present study. This may be explained how only the ΔCTL-cold pre- post is significant due to the complexity of factors that can be influenced blood flow and neurotransmitters in a day (hydration, fatigue, mood...) and can be control by use the Δ with the CTL environment. Moreover, no significant difference was observed with the maximal suspension time, where this endurance measure at cold seem be maintain.

Strategies used and limitations

The strategies developed from the present research seemed to protect the crew during their expedition in Antarctica. However, it is difficult to attribute a value to the different strategies due to the absence of a control group. However, with the knowledge of previous studies (Halsey and Stroud 2012; Stroud 2001) and the present study, the high-caloric diet seems to be an effective way to preserve the lean mass by an important energy intake to support an energetic balance. Furthermore, the physical preparation needs to be sufficient for the crew to bring the necessary amount of food (weight of this food) during a ski-pulling trek in complete autonomous expedition and should use low weight and effective material for clothes and equipment This should not be minimized like in previous expeditions in other extreme environments where a lack of preparation can decrease performance and increase risks (Halsey & Stroud, 2012;. Stroud, 2001, Frykman et al. 2003).

The present study used newest material technologies, weight from clothing and equipment increase the energy expenditure during an expedition (Teitlebaum and Goldman 1972). However, they are essential in the protection against cold injuries (Geng et al. 2006). The improvement of material technology can help to protect against extreme environment (cold, wind...) at lower weights, inducing lower energy expenditure. A previous study (Teitlebaum and Goldman 1972) showed that multilayer clothing weighed 11.19 kg for an Arctic expedition. However, this expedition used multilayer clothing during the progression that was lighter (~6kg) than in the Teitlebaum and Goldman(1972) study, suggesting a lower energy expenditure due to new technology clothing.

Even if the present study sample is larger than the majority of expedition crews, the physiological variation makes the analysis complicated to interpret with this small sample, where a strong risk of Type 2 error can result. Furthermore, it is difficult to analyze gender influence with this small sample. However, even with the small sample, this study highlights some significant differences in the lean mass changes with gender, showing the importance to continue research in gender differences in physiological changes in an extreme environment when the participant return at home and have to retrieve their normal work, often without additional recuperation time .

3.3.7. Conclusion

Maintenance of lean body mass and muscular fitness appeared to help improve specific aerobic capacity in adventurers on an Antarctic expedition. Furthermore, acclimatization to cold seems to show a lower energy demand at submaximal exercises. The maintenance and even improvement of physical fitness may be explained by strategies that include modern material technology, high caloric intake and physical preparation. These countermeasures may be crucial in preventing lean body mass loss and physical ability decay in an extreme cold environment. However, further research needs to be done to know the importance of the different strategies.

3.3.8. References

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3.3.9. Figures

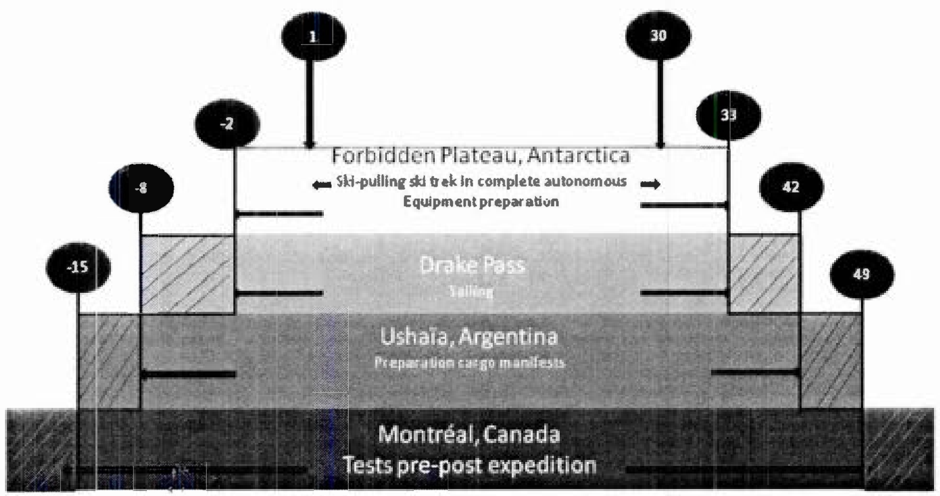

Figure 3. 1: Expedition timeline

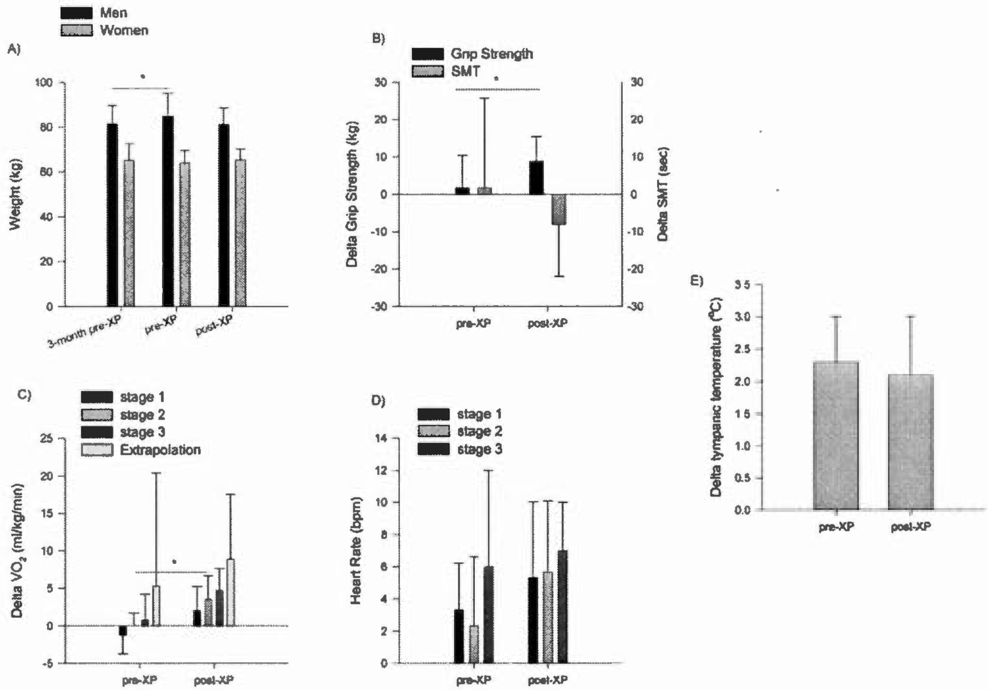

Figure 3. 2: Weight and delta-CTL-cold environment test A)Relationship between weight and time by sex, B) Relationship between ΔCTL-cold for muscular parameters and time, C) Relationship between ΔCTL-cold for VO_2 at submaximal exercise parameters and time D) Relationship between ΔCTL-cold for HR at submaximal exercise parameters and time E) Relationship between ΔCTL-cold for tympanic temperature at the end of tests and time; 3 month pre-XP: preparation pre-expedition 3 month before the expedition; pre-XP:pre-expedition, post-XP: post-expedition; *: $p \leq 0.05$

3.3.10. Tables

Table3.1: Participants anthropometric characteristics

	Pre-expedition			Post-expedition			*P* values (ES)		
	Women	Male	Group	Women	Male	Group	Women	Male	Group
Weight (kg)	64.1±5.5	84.9±10.2	74.5±13.6	65.5±4.9	81.1±7.6	73.3±10.3	0.105	0.147	0.422 (0.09)
Height (cm)	172±7	183±5	177±8	N/A	N/A	N/A	N/A	N/A	N/A
BMI (kg/m^2)	21.6±1.9	25.5±2.3	23.5±2.8	22.1±2.0	24.3±1.9	23.2±2.1	0.116	0.133	0.481 (0.12)
Body Fat (%)	25.7±6.7	18.2±8.0	22.0±7.7	24.6±6.3	15.5±7.5	20.1±7.9*	0.158	0.147	0.014* (0.24)
Lean mass (kg)	45.4±4.4	66.7±7.3	56.1±12.8	47.1±4.1*	66.0±5.7	56.5±11.2	0.040*	0.581	0.345(-0.03)

Mean ± SD (ES, Cohen's *d* effect size); * p≤0.05

Table 3. 2: Physical fitness results

	Pre-expedition			Post-expedition			*P* values (ES)		
	Women	Male	Group	Women	Male	Group	Women	Male	Group
Muscular tests									
Grip Strength (kg)	72.0±5.3	126±7.9	99.0±30.2	74.7±17.0	115.0±13.9	94.8±26.1	0.655	0.109	0.464 (0.15)
SMT (sec)	38±17	73±10	55±23	55±47	61±20	64±34	0.655	1.000	0.446 (0.31)
CMT (sec)	180±79	189±46	185±58	150±57	139±48	164±50	0.109	0.593	0.133 (0.39)
LP_{LL},1MR_{ext}(lb)	221±28	405±78ɫ	295±110ɫ	279±23	492±133ɫ	364±135ɫ*	0.180	0.180	0.031* (0.56)
LP_{RL}1RM_{ext} (lb)	223±31	420±56ɫ	302±114ɫ	271±24	532±190ɫ	376±172ɫ	0.285	0.180	0.124 (0.51)
Chin-Up1RM_{ext}(lb)	77±11	119±3	98±24	76±10	114±9	95±23	0.593	0.285	0.241 (0.13)
Aerobic tests									
SMAT									
VO_2 peak (ml/kg/min)	38.9±1.7	42.8±5.4	40.8±4.2	42.6±4.6	51.3±7.6	46.9±7.4*	0.109	0.102	0.027* (1.01)

VO_2 peak (ml/kg lean mass/min)	55.6±4.4	54.1±2.9	54.9±3.4	58.7±1.0	62.4± 14.1	60.5±9.2	0.285	0.180	0.104 (0.81)
HR peak (bpm)	176±6	187±6	182±8	187±10	186±7	186±8	0.109	1.000	0.262 (0.5)
VE peak (L/min)	98.3± 11.9	143.7±8.4	121.0± 26.5	93.7±7.6	142.7± 16.2	118.2± 29.1	0.109	1.000	0.560 (0.10)
%VO_2 at VT	69.8±3.6	60.9±4.8	65.3±6.2	82.9±5.1	71.6±7.8	77.2±8.5*	0.109	0.109	0.003* (1.60)
VO_2 at VT (ml/kg/min)	27.2±2.1	26.0±2.8	26.6±2.3	35.1±1.8	36.4±4.1	35.8±2.9*	0.109	0.109	0.027*(3.52)
MARS									
VO_2 peak (ml/kg/min)	42.8±4.7	45.0±3.6	44.0±3.9	41.6±3.3	47.9±9.3	44.7±7.0	0.655	0.655	1.000 (0.12)
VO_2 peak (ml/kg lean mass/min)	59.1±3.3	56.2±4.5	57.6±4.0	60.2±2.9	59.5± 16.1	59.8±10.4	0.276	1.000	0.916 (0.28)
HR peak (bpm)	193±13	192±3	193±7	192±4.9	187±3.8	189±4	0.655	0.180	0.241 (0.70)
VE peak (L/min)	115.0± 10.0	145.7±7.5	130.3± 18.6	108.0± 12.8	131.0± 5.6	119.5± 15.4*	0.109	0.180	0.037* (0.63)
%VO_2 at VT	85.4±3.5	76.2±3.8	80.8±5.8	89.6±5.1	88.7±1.1	89.1±3.3	0.285	0.109	0.020* (1.76)
VO_2 at VT (ml/kg/min)	35.8±3.5	33.6±3.3	34.7±3.3	37.3±3.5	42.5±8.7	39.3±6.6	0.285	0.109	0.046* (0.88)

Mean ± SD (ES, Cohen's *d* effect size); * $p \leq 0.05$; SMT, suspension Maximal Time, CMT, Chair Maximal Time; LP_{LL}, $1RM_{ext}$, Leg Press left leg 1 Maximal Repetition, LP_{RL}, $1RM_{ext}$, Leg Press Right leg 1 Maximal Repetition; SMART, Specific Maximal Aerobic Test; VT, Ventilation Threshold;MARS, Maximal Aerobic Running Speed; ł: malfunction from a device n-1

Table 3. 3:Physical performance at ambient vs cold temperatures

	Pre-expedition (CTL / Cold)			Post-Expedition (CTL / Cold)			*P* values (ES) (CTL / Cold)		
	Women	Male	Group	Women	Male	Group	Women p	Male	Group
Grip strength (kg)	70.3±2.1 / 68.0±4.0	120.7±11.7/ 119.3±3.1	95.5±28.6/ 93.7±28.3	75.3±18.6/ 69.3±17.0	107.0±4.4/ 96.3±11.0	91.7±20.7/ 82.8±19.6	0.593/ 0.655	0.276/ 0.109	0.605 (0.15)/0.171 (0.45)
SMT (sec)‡	59±48/ 60.7±32.7	167‡/ 156‡	86±67‡ / 85±55‡	44±38/ 46±44	92‡/ 117	56±39/ 64±50	0.109/ 0.285	N/A	0.148 (0.55)/0.170 (0.40)
Aerobic submaximal test									
$VO_{2\ Stage1}$ (ml/kg/min)	16.7±0.6 / 19.3±1.2	17.7±1.2/ 17.3±3.1	17.2±0.98/ 18.3±2.3	17.3±2.1 / 14.7±5.0	16.7±1.5 / 15.3±1.5	17.0±1.7/ 15.0±3.3	0.564/ 0.180	0.180/ 0.157	0.888 (0.14)/ 0.066(1.16)

HR $_{Stage1}$ (bpm)	103±4/ 101.±7	101±5/ 96±5	102±4 / 99±6	101±8/ 95±11	97±6/ 92±2	99±7/ 94±8	0.593/ 0.285	0.655/ 0.285	0.425(0.53)/ 0.093 (0.71)
VO_2 $_{Stage2}$ (ml/kg/min)	21.7±0.6 / 21.3±1.2	21.3±0.6/ 21.7±2.5	21.5±0.5 / 21.5±1.8	21.0±1.7 / 16.3±4.2	21.3±2.3 / 19.0±2.6	21.2±1.8/ 17.7±3.4 *	0.655/ 0.102	1.000/ 0.109	0.683 (0.23)/ 0.027*(1.40)
HR $_{Stage2}$ (bpm)	115±2/ 112±6	107±4/ 105±2	111±5/ 109±5	109±7/ 103±12	106±5/ 100±5	107±6/ 102±8*	0.285/ 0.109	1.000/ 0.109	0.314 (0.72)/ 0.025*(1.05)
VO_2 $_{last\ stage}$ (ml/kg/min)	24.7±0.6 / 23.3±1.2	26.0±1.0/ 25.7±4.5	25.3±1.0 / 24.5±3.2	25.0±1.7 / 19.0±4.4	26.3±2.5 / 23.0±4.0	25.7±2.1/ 21.0±4.3 *	0.584/ 0.180	0.785/ 0.102	0.589 (0.24)/ 0.042*(0.92)
HR $_{last\ stage}$ (bpm)	130±5/ 121±4	121±8/ 117±5	125±8/ 119±5	124±8/ 118±6	121±6/ 113±8	122±6/ 115±8	0.593/ 0.285	1.000/ 0.414	0.507(0.90)/ 0.241(0.99)
VO_2 $_{max\ extrapolated}$ (ml/kg/min)	45.4±6.8 / 35.2±5.5	55.7±9.2/ 55.2±12.8	50.5±9.0 / 45.2± 14.1	48.0±6.4 / 33.2±9.3	54.7±3.0 / 51.7±6.4	51.3±5.8/ 42.5±12. 4	0.593/ 1.000	1.000/ 0.593	0.847 (0.11)/ 0.517(0.20)

Tympanic temperature at the end (°C)	36.4±0.3 / 34.4±0.5	36.1±0.9/ 33.6±1.0	36.3±0.6 / 34.0±0.8	36.7±0.5 / 34.3±1.1	36.5±0.6 / 34.8±1,6	36.6±0.5/ 34.6±1.3	0.285/ 0.593	0.109/ 0.180	0.058 (0.54)/ 0.345 (0.56)

Mean±SD (ES); * $p \leq 0.05$; Ctl: control, Cld: cold; ƚ: device malfunction n-2

CHAPITRE IV: RÉPONSES PHYSIOLOGIQUES DURANT UNE EXPÉDITION EN ANTARCTIQUE

4.1. Mise en contexte

Les changements physiologiques observés et expliqués aux chapitres précédents ne permettent malheureusement pas de comprendre les réponses physiologiques durant l'expédition. Les mesures physiologiques durant une expédition polaire en complète autonomie sont restreintes par plusieurs contraintes telles que le poids de l'équipement où chaque milligramme compte et la difficulté à prendre des mesures standardisées avec la fatigue accumulée. Il a tout de même été possible de prendre certaines données et même au besoin de les transmettre via satellite. Le chapitre suivant propose certaines mesures rencontrant les restrictions de l'expédition tout en fournissant des données permettant de suivre l'équipe au point de vue physiologique et psychologique.

4.2. Résumé

Les explorateurs de l'Antarctique sont exposés à un environnement extrême sans avoir accès à une équipe de sauvetage dans un délai acceptable en raison de l'environnement. Objectif: L'objectif de cette étude était de mesurer et d'observer les réponses cognitives et physiologiques des explorateurs de l'Antarctique. Méthodes: L'équipage de six explorateurs (trois femmes et trois hommes) a effectué une expédition en Antarctique. Le cortisol salivaire, la force de préhension, et la capacité vitale forcée ont été mesurés avant d'embarquer pour l'Antarctique, avant de

commencer l'expédition sur le continent, après l'expédition sur le continent, et après l'arrimage en Argentine. La température orale a été prise chaque semaine et l'échelle de l'humeur (PANAS), le temps de réaction simple et le Stroop ont été pris à la fin de chaque semaine pendant l'expédition. En outre, un échantillon de cheveux a été pris avant et après l'expédition. Résultats: Aucune différence significative n'a été observée pour la capacité vitale forcée, la force de préhension, la température orale, le test PANAS, Stroop et le cortisol salivaire au cours de la progression dans l'Antarctique. Cependant, le cortisol des cheveux montre un stress important au cours de l'expédition (2,42 ± 0,5pg/mg vs. 16,7 ± 10,0 p/ mg, pour le mois avant l'expédition vs le mois en Antarctique, respectivement, $z = -2{,}201$, $p = 0{,}028$) et le temps de réaction simple moyenne a diminué légèrement entre la fin de la semaine 1 et la fin de la semaine 3 (455,4 ± 44,0ms vs. 416,8 ± 38,9 ms, t (5) = 3,897, $p = 0{,}030$, $d = 0{,}93$) .Conclusions: En conclusion, les capacités cognitives et les changements physiologiques ne semblent pas être affectés ou du moins diminuer de façon drastique au cours de l'expédition, excepté pour le cortisol des cheveux.

4.3. Article

4.3.1. XP-Antarctik Expedition: Effect of month long autonomous expedition in Antarctica onPhysiological Responses,Body Composition and Human Performance

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4.3.2. Abstract

Purpose: To observe during a 30 day sled-pulling expedition in Antarctica the physiological and cognitive responses of explorers. **Methods:** A 6 member crew (3 women and 3 men) performed a grip strength and spirometry before boarding for Antarctica, before and after the expedition on the continent, and after landing. The oral temperature, the mood scale (PANAS), simple reaction time (SRT) and Stroop test were taken at the end of every week during the expedition. Furthermore, a hair sample was taken before and after the expedition to measure long-time effect of stress, thus the saliva sample was taken before and after sailing to observe at punctual time the stress makers level. Ultrasound anthropometric measurement was performed before and after sailing and pre-post expedition. **Results:** The hair cortisol shows a stress effect (2.42±0.5 vs 16.7±10.0 pg/mg, before and after, respectively, $t(5)=-3.804$, $p=0.013$), but no significant difference in saliva cortisol. No significant difference was observed for ultrasound measurements, grip strength, spirometry, oral temperature, PANAS, SRT and Stroop measurements. **Conclusion:** Based on the results, the preparation for this expedition (nutrition, latest technology material, physical preparation) seems to appear to be some of the key aspects during the expedition to countermeasure detrimental effects on physiological and cognitive outcomes measured in the current study.

Key Words: Body composition, Expedition, high-caloric diet, muscle mass, body fat composition, Antarctica expedition, monitoring, human performance, cortisol, reaction time

4.3.3. INTRODUCTION

Antarctica expeditions may have important physiological and psychological effects on explorers that confront this extreme environment. Cold exposure affects physiological parameters in the short and long term, where socialization, cognitive reaction, and physical responses can be degraded (Stocks et al. 2004). Cognitive performance at cold exposure compounded by a stressful environment can be a significant issue as described in previous studies where the risk of injuries can increase (Lieberman, Castellani, and Young 2009; Reed et al. 2001) .Recently, an Antarctica expedition (XP-Antarctik) was implemented for a month (30 days) long ski pulling sledge excursion in complete autonomy set on climbing various uncharted summits in the Forbidden Plateau. The complete autonomy was defined as using only human effort to transport all necessary equipment, food and waste, but also being able to respond autonomously to urgent events, and if required, help provided by satellite telephone via a Montreal based medical crew.

Physiological responses

It has been well reported that various physiological responses at cold can affect human performance during expeditions (Stroud 2005, Frykman et al. 2003). Specifically, muscle force, as measured by maximal grip strength, has been shown to decrease when hands are exposed to cold.(Cheung 2015; Muller et al. 2014) The consequence of a loss in functional hand capacity can be troublesome for several expedition tasks, such as ice climbing, cooking, and setting up camp and, thus, impact the ability on being able to maintain autonomous fulfillment(Anttonen, Pekkarinen, and Niskanen 2009; Havenith, Heus, and Daanen 1995) . Furthermore, the loss of general strength is not only attributed to cold, but for grip strength has also been shown to be linked to important caloric intake deficits(Frykman et al. 2003; Stroud 2001).

The pulmonary function has also been indicated as being possibly limited when exposed to cold during intense exercise(Davis et al. 2002; Therminarias et al. 1998). In fact, bronchoconstriction has been observed to increase airway resistance to pulmonary airflow thereby reducing pulmonary alveoli ventilation(Davis et al. 2002). Thus, exercise-induced bronchospasms to cold exposure could limit ventilation (V_E) during high intensity exercise and has the potential to decreasing physical performance(Rundell and Jenkinson 2002). As well, pulmonary function today can be easily assessed by handheld spirometers, making them attractive for expeditions, where two important components can be measured: 1) the forced vital capacity (FVC) that indicates the maximal amount of air that can can be expired after a maximal inspiration, and 2) the expired volume in 1 sec (FEV_1) after the beginning of a forced expiration that measures airflow limitation(Celli et al. 2004). Therefore, the interest for measuring airflow limitation during prolonged cold exposure could help explain if the limitation in daily distance travelled during a polar expedition is attributed to a decrease in V_E.

Another important factor of Antarctica expeditions is the maintenance of core body temperature. Long exposition to cold environments can decrease core body temperature, where even mild cold, such as 16°C, causes a significant lower rectal temperature compared to an environment at 22°C(Van Marken Lichtenbelt et al. 2002). Furthermore, freezing temperatures cause a decrease in skin temperature where the risk of frostbite injury increases significantly(Anttonen, Pekkarinen, and Niskanen 2009; Havenith, Heus, and Daanen 1995). The impact can be greater during prolonged exposures, such as prolonged expeditions, as in the present study, due to body fat loss that can be associated to a potential negative caloric balance, thereby affecting thermoregulation and body insulation due to a reduction in subcutaneous fat thickness(Frykman et al. 2003; Halsey and Stroud 2012; Stroud 2001)

Body composition

The subcutaneous body fat is part of the insulation to preserve body heat when the human body is exposed to cold. However, the effect of the Antarctic environmental stress on body composition is not entirely understood (Simpson 2010). It has been reported that the two major factors affecting body composition are the total caloric intake and energy expenditure, that are both elevated by exposure to cold temperatures (Frykman et al. 2003; Poehlman, Gardner, and Goran 1990). In fact, cold exposure increases energy expenditure (Oksa et al. 2004). However, many contradictions between studies leaves the underlying mechanisms of energy expenditure and food intake unclear in extreme environments (Halsey and Stroud 2012; Simpson 2010). The body composition variations in Antarctica have been observed in previous studies in order to propose a way to estimate the energy expenditure and energy intake used to sustain the workload, protect from severe weight loss, and mostly protect from muscle loss (Frykman et al. 2003; Halsey and Stroud 2012; Poehlman, Gardner, and Goran 1990). Previous studies have estimated energy expenditure requirements in order to provide an adequate diet during Antarctica expeditions. However, the estimations provided by these studies had no clear consensus on the quantity, the composition, and the impact of the nutriments for both women and men, and, especially, knowing that most of the estimations were obtained from small samples of men (Campbell 1981; Frykman et al. 2003; Poehlman, Gardner, and Goran 1990). Energy expenditure in Polar conditions can also be affected by many aspects, such as the weight of clothes, particularly the multilayer system (Teitlebaum and Goldman 1972), the range of movement limited by the clothing, and the weight load shifted from the center of gravity of the body to the extremities related to the gloves and boots (Soule and Goldman 1969).

Furthermore, walking in the snow, depending on the conditions and wind speed, increases the energy cost (Simpson 2010).

The strategies proposed by previous studies in order to protect humans from important weight and lean mass loss has been reported in a 1995 study (Tsintzas et al. 1995), where the diet contained about 70% energy in carbohydrates to enhance endurance. The underlying principle was that pulling a sled at lower average speed is less affected by body oxygen limitations and a high caloric ingestion probably increases the time to sustain low aerobic rate exercise (Halsey and Stroud 2012). Early studies postulated that protein needs were high due to the hard physical work and loss of lean mass during Polar expeditions and that high levels of protein ingestion could be an effective countermeasure (Stroud 1995, Hasley and Stroud 2015, Makinen 2003). Nonetheless, it was observed by Speth and Speilmann (1983) that a better strategy to protect the lean mass is to minimize the energy deficit by providing an adequate amount of carbohydrates to protect the protein stores from being converted to glucose as an energy source.

Cognitive performance and emotions

The cognitive function has been shown to decrease at cold environment exposure(Marrao et al. 2005). Some authors, however, seem rather point to the "isolation" even if explorers in simulated missions could talk via internet to their family(Bishop, Grobler, and Schjoii 2001; Kanas et al. 2009; Sandal, Leon, and Palinkas 2006). As well, studies to measure cognitive and emotional changes that have used reaction time and emotion scales indicated that exposure to extreme environment can result in a social effect of isolation among group members that results from an impairment in reaction time and vigilance(Paulus et al. 2009). Indeed, expedition stress can play an important role on mental and physical performance and may alter cognitive and emotional responses(Paulus et al. 2009).

It is for the above mentioned reasons that in the current study body composition and mental qualities were monitored. Thus, the following physical and mental properties were monitored: grip strength, respiratory capacity, core temperature, body composition (% body fat and lean mass), biological stress markers, and cognitive. Consequently, these measurements permitted to follow the evolution of the explorers during the expedition. Therefore, the primary aim of the current study was to observe in a mixed sex crew during a month long modern Antarctica expedition the impact of high-energetic diet rations, and physical preparation on physiological, body composition and cognitive responses. The second aim was to use weekly reports from the crew via internet communication to have physiological and cognitive response parameters transmitted for the potential of telemedicine tracking. The hypothesis was that the use of a high-energetic diet to meet the energy requirements for a modern day expedition in Antarctica, using new technologies material and physical preparation, would preserve crew lean body mass in the Antarctica environment, as well, as preserving grip strength, pulmonary function, body temperature, both body fat and lean mass, and that simple reaction time would decrease during the expedition. It was also expected that positive emotions would decrease and that negative emotions would increase in conjunction to marked increases in salivary cortisol.

4.3.4. METHODOLOGY

The timeline of events/measurements is presented in Figure 4.1. The study was approved by the University of Quebec in Montreal ethics committee and informed consent was obtained from all individual participants included in the study. Furthermore, the following expedition description was described in detail elsewhere (Parent et al., in submission).

Explorers

The crew was composed of 6 members (3 men and 3 women, 25± 4 years old). The crew participated in a 7-day acclimatization and logistical pre-expedition in the Columbia ice field in the Canadian Rockies to prepare and to review team techniques, physical and psychological challenges, and to observe how the explorers responded to a high-energetic diet in extreme environment. It is important to note that one man was sick during the expedition and had only the liquid diet during 1 week.

Expedition preparation

In addition to the pre-expedition preparation, participants kept a daily diary of their work activities as adventure tourism guides in the 8 months leading up to the Antarctica expedition. A log was used to keep track of the distance covered during adventure, calories consumed, and heart rate (monitored with heart rate monitor, RS800, Polar, Fi). Monitoring and communication with the physical preparation coach was mostly through the internet (tele-training). On top of their physically demanding work as tourism guides, specific callisthenic exercises were also used to increase their individual strength and endurance.

Energy expenditure prediction for the expedition was determined in a laboratory setting using a self-propelled treadmill (Hi-Trainer, Bromont, Qc, Canada) to simulate a cross-country skiing load to estimate the activity intensity that was reached in previous studies on expeditions at cold temperatures (Budd 1965; Frykman et al. 2003; A. Simpson 2010). The estimation was calculated with an estimated duration time of 12-15 hr per day (~6-8 METS, 460-600 kcal/hour). Furthermore, participants were encouraged to gain weight (% body fat and muscle) for physical sustainment during the expedition (energy store).

Expedition details

The explorers flew to Ushuaia, Argentina, one week before sailing across the Drake Passage to familiarize crew and prepare cargo. As illustrated in Figure 1, the Antarctica expedition was composed of sailing across the Drake passage (~1700 km sea travel), followed by a month long expedition in Antarctica on the Forbidden Plateau in complete autonomy, and ended upon returning to Ushuaia by sailing again across the Drake Passage and remaining there for one week before returning to Canada

The majority of time of the sledge pulling skiing expedition was spent in isolation in a mountainous area of the Forbidden Plateau, where communication (radio and satellite), is limited and cannot be reached by helicopter if an emergency rescue needs to be done. Noteworthy, is that one crew member became ill during the expedition, but the punctual medical attention and rest provided in the field was sufficient to carry on. However, the resting time for this crewmate caused the other crew members to abandon some planned summit climbs. Nevertheless, satellite phone and wireless (satellite) connections to social media were part possible and encouraged.

The explorers advanced most of the time on skis while each crew member initially pulled approximately 100 kg in an equipment-laden sled and rucksack. Average daily progress time was 10-15 hours with a daily sunshine duration of 12h. The food intake per day per person was calculated and contained freeze-dried food and caloric bars with mineral additives (Happy Yack and Xact nutrition, Montreal, Qc, Can) that were around 5800 Kcal (39% fat, 46% carbohydrate and 14% protein) for the two first weeks and 6500 Kcal (43% fat, 42% carbohydrate, 15% protein) for the remaining weeks. This amount of calories was set in individual packages for every meal, and the team was instructed to entirely consume all prepared meals. The same instruction was given for snacks during the day. If the crew didn't consume the entire package food by day, it was required to advise the scientist in charge that remained on the ship. The scientist in charge was able, if needed, to communicate with a medical team (ground control) in Montreal for further assistance.

Weather conditions were typically what is expected for a February and March time window, which is the end of the first quarter and where the temperature decreases drastically compared to December and January. Furthermore, the weather was most of the time, whiteouts with visibility and contrast severely reduced by blowing snow juxtaposed to terrain elevation and undetectable troughs, with temperatures ranging from -20 to -40 °C. On the first day near shoreline the temperature was -20°C and several days later on the Forbidden Plateau averaged -40°C. The highest summit reached was around 2200 m and the altitude on the Forbidden Plateau averaged 1400m. The total distance traveled was more than 160 km according to open source satellite pictures.

The clothing for the expedition was the latest technology available and used the layer method to provide insulation: a base layer with merino wool, a mid-insulation layer with light weight garments, an insulated (Mammoth, Gore-Tex, Seon, Switzerland) wind shell, and for resting time or extreme temperature another outer shell was available. The clothing weight was around 6 kg (pants layers~0.8 kg, shirts, jackets and parkas layers~3kg and boots, socks and underwear layers ~1,9 kg).

The camp was mounted and dismounted on a daily basis, comprised one portable tent (space station, Mountain Hard Wear, CA, USA) ,except during climbing unknown summits where the team was separated, 2 women and 1 men stayed at the base camp with the daily base tent and the other half brining a small portable tent (Trango, Mountain Hard Wear, CA, USA) and the strict minimal equipment. The sleeping arrangements within the tent were with individual sleeping bags certified up to -34°C (Lamina Z Bonfire, Mountain Hard Wear, CA, USA).

Physiological measurements

The pulmonary function, FVC and FEV_1, and the grip strength were measured before boarding on the ship, before disembarking the ship onto the continent, re-boarding the ship from the continent, and after un-boarding the ship in the port of Ushaïa. The spirometry protocol followed American Thoracic Society (ATS) standards (Miller et al. 2005) using a handheld portable spirometer (SpiroThor, Thor, Budapest, Hungary) to measure FVC and FEV1.

The grip strength was measured according to the Canadian Society of Exercise Physiology standards (CSEP/ SCPE 2003) with a hand held dynamometer (Lafayette hand dynamometer, Lafayette Instrument Company, Lafayette, Indiana, USA). Briefly, the explorer needed to squeeze the dynamometer using a handgrip the as forcefully as possible (maximal) beginning with the dominant hand. The procedure was performed twice. Afterwards, the procedure was repeated with the non-dominant hand. The results presented are the best from each hand.

The oral temperature was taken according to established standards (Livingstone et al. 1983; Moran and Mendal 2002), where the explorer had their temperature taken in the morning at the same time of the day inside their tent, without previously stepping outside and drinking any type of beverage. The oral temperature was taken with the same digital thermometer (Digital Pro, Physiologic, San Diego, California, USA) and the temperature was noted every week with an accuracy of ±0.1°C.

Body composition assessment

Weight was measured to the nearest 0.1kg using an electronic platform scale (BWB-800p, Tanita, Japan) and the height with a medical scale (Detecto D-439, MO, USA) with a precision of ±0.5 cm. Ultrasound anthropometric measurements were taken using a portable ultrasound device (Biometrix, Intralametrix, USA) to estimate % body fat (%BF) and lean mass from 7 skin sites based on the equation of Jackson Pollock (Jackson and Pollock 1985). The ultrasound assessment was performed before boarding the boat in Ushuaia, Argentina, before landing on the continent, upon returning from the continent and disembarking from the boat in Ushuaia, and at UQAM at the end of the assessments (end of the first week of the return of the crew in Montreal). This last measurement was taken in the same time of a Dual-energy X-ray absorptiometry (DEXA, GE Prodigy Lunar, Orlando, USA) calibrated as instructed by supplier to compare the ultrasound measurements to the reference (Gold Standard) measurement, DEXA (Wagner 2013). Previous studies have shown that the ultrasound technique is a valid method for assessing %BF (Wagner 2013).

Cognitive performance, emotions and stress marker

The simple reaction time, Stroop test, effort perception (OMNI scale), and Mood Sale (PANAS) was practiced at Ushaïa before the expedition and were set to be taken every week during the excursion. However, the second week was not taken due to crew forgetfulness. The simple reaction time and the Stroop test were measured using a portable tablet (ToughPad FZ-G1, Panasonic, Kadoma, Osaka Japan). The instructions were to press a button on the screen as quickly as possible when a black square appeared, using the dominant hand placed on the bottom center of the tablet (on the Windows icon). The average and the best time for the simple reaction test for 10 tries were noted. The second task was a Stroop test (homemade application) where the explorer needed to press the color of the writing (writing in another color) on a circle color choice as quickly as possible. The mood scale was measured by the validated French version of the PANAS (Gaudreau, Sanchez, and Blondin 2006), where the question was: During the last week, can you describe how you felt? The scale contains 20 items for rating emotions on a 5-point Likert-type scale. The positive and negative emotions are analyzed to rate the level of both. The OMNI scale used, containing pictograms, is a validated effort perception scale (Robertson et al. 2003; Utter et al. 2004) ranging from 0 to 10, where 0 is extremely easy and 10 is extremely hard.

Salivary and hair cortisol were taken according to established standards(Stalder and Kirschbaum 2012) . The saliva was collected in a Salivette test tube (Sarsted, Romelsdorf, Germany) and was taken before boarding, before going on the continent, returning to the ship from the continent, and after the un-boarding from the ship and was preserved in a freezer in the ship to be analyzed on the return to Montreal. Hair samples were taken in the preceding month before the expedition and taken after the expedition in order to analyses cortisol changes that may have occurred during the expedition. The hair samples were preserved according to technique used by Stalder and Kirschbaum (2012). The salivary cortisol is presented as percent of the expected baseline for each explorer as a function of their age, sex, time of the day (Aardal and Holm 1995).

Statistical Analysis

The results are presented as mean ± standard deviation. Due to the sample size, the Shapiro-Wilk test was used to test the normal distribution (Razali and Wah 2011). The effect of the expedition (pre vs. post) on physical fitness was analyzed using a nonparametric test for two related samples (Wilcoxon for sex analysis, presented pooled when not significant) for the data that was not normally distributed and, a paired t-test for the data that was normally distributed. The factor of time was analysed using an ANOVA for repeated measures with LSD correction when the data was normally distributed and with the Friedman test (for repeated measures) when the data was not normally distributed. Effect sizes were calculated as described by Cohen for the non-parametric tests and, t-test, r for the Wilcoxon(Rosenthal and DiMatteo 2001) and, the partial eta square (n^2_p) for the ANOVA tests. Significance was established at $p<0.05$. The statistical analysis was performed using SPSS Statistic 20 (IBM, USA).

4.3.5. RESULTS

Pulmonary function

The FVC (Fig. 4.2A and Table 4.1) did not significantly change during the expedition. However, a significant difference was observed between sex, as expected, (Z=-1.964,p=0.05,d=10.4)(Aggarwal and Agarwal 2007). Same observation for FEV_1, where no significant differences were observed at various time points during the expedition (Table 2), while, as expected, a significant difference was observed between sex (Z=-1.964,p=0.05, d=10.4). The FEV_1/FVC ratio remained unchanged during the entire expedition.

Grip strength

The grip strength showed no significant difference during the expedition (Fig. 4.2B) (F(1,4)=4.8,p=0.093, n_p^2=0.548). As expected, sex had an effect on grip strength (Z=-1.964, p=0.05,d=10.4) (Table4.1).

Oral temperature

The oral temperature (Fig.4.2C) showed a significant difference in the measurements (F (1,4)= 7.50, p=0.05, n^2_p=0.65), where the significant differences are between the last day of sailing (36.6±0.2°C) and the end of week 1 (36.4±0.1°C, p=0.02,d=1.3), end of week 3 (36.4±0.1°C, p=0.01, d=1.3) and after landing (36.4±0.1°C, p=0.01,d=1.3), but did not significantly differ for the other time points, as well as for the pre-post expedition measurement . No significant difference was observed between sex (between, Z=-1.53, p=0.13, d=1,6 and after the expedition before boarding, Z=-0.218, p=0.83, d=0.2)

Body composition

The figure 2D and E shows the anthropometrics results pre-post expedition. The results show the observation on the body composition. No significant difference was observed in the percentage of body fat (%BF) and lean mass pre-post expedition and pre-post sailing ($F(1,4)=0.022, p=0.891, n^2_p=0.007$ for %BF and $F(1,4)=2.788$, $p=0.194$, $n^2_p=0.482$).

Furthermore, no significant difference between the DXA and the ultrasound was observed (22.6±5.7 %BF with the DEXA and 23.6±7.6 %BF with the ultrasound, t(4)= -0.296, p=0.782, d=0.15 and 55±11 kg of lean mass with the DEXA and 57±15 kg of lean mass with the ultrasound, t(4)=1.483,p=0.198, d=0.15). Noted that one participant was not available to compare DEXA and ultrasound method after the expedition.

Cognitive and Emotions responses

The reaction time (Fig. 4.3) was not affected ($x^2(4)=5.20$, p=0.27, r=1.14) as for the Stroop test ($x^2(4)=7.28$,p=0.12,d=1.35). Sex differences were not significantly different for the reaction time (Z=-0.66, p=0.51, d=0.70). Furthermore, the Mood scale (PANAS questionnaire) was not significantly different ($x^2(3)=4.88$, p=0.18,r=1.10) for positive emotions ($x^2(3)=$ 3.08, p=0.38,r=1.54) and not significantly different between sex (Z=-0.66, p=0.51, d=0.70).

Effort perception

The effort perception with the OMNI scale showed a significant difference ($x^2(3)=8.46$, p=0.04, r=1.45) where a higher effort perception after progression than before the progression (4.7±1.6 vs 7.4±1.5, before the progression vs after the progression respectively, Z=-2.04, p=0.04, *r*=1.02) but not with the other time points. However, no significant difference was observed between sex (Z=-0.89, p=0.38, d=0.99) (figure 4.3).

Cortisol

There were no significant differences between salivary cortisol compared to their theoretical baseline (Aardal and Holm 1995) for the different time points (Fig. 4.3), F(1,4)=5.85, p=0.07, n^2_p=0.59 . Furthermore, no significant difference was observed between sex (Z=-0.65,p=0513,d=0.55) (table2). However, hair cortisol (Fig. 3) levels showed a higher significant difference for the month during the expedition than the month prior to the expedition (2.4 ±0.5 pg/mg during the month pre-expedition vs 16.7 ± 9.2 pg/mg during the expedition month, t(5)=-3.804, p=0.013, d=2.195). No significant difference was observed between sex (Z=-0.218,p=0.827,d=0.179 pre-expedition and, Z=-1.107, p=0,268,d=1.013 post expedition).

4.3.6. DISCUSSION

The main finding of the study was that during the progression time in Antarctica; the crew did not lose %BF or lean mass during the expedition, suggesting adequate food intake vs energy expenditure in order to maintain lean mass. Moreover, the maintenance of % BF during the expedition seems to indicate adequate energy intake to fuel the energy requirements of the expedition demand without excessively depleting body energy stores and the impact on the lean mass like in previous studies (Frykman et al. 2003; Halsey and Stroud 2012; Stroud 2001).

As well, no significant differences were observed in pulmonary function, grip strength and oral temperature during the expedition, as well as in the reaction time. Furthermore, and opposite to what was expected, there were no significant changes in scores on the Mood Scale., The perception of effort, however, did significantly increase after vs before the expedition. Finally, the stress marker, cortisol, measured from hair samples, did show a significant increase, however, it was not possible to observe significant differences with punctual salivary cortisol measurements. Thus, the physiological and cognitive measurements setup was feasible on a weekly basis during a ski-pulling sledge excursion and proposed useful tools for future monitoring of Polar expeditions. There are, however, some limitations that need to be presented before proceeding further with the discussion.

Limitations

One of the important limitations of the current study is sample size particularly by sex, and for future studies, it would be crucial to have access to a greater number of explorers. However, to the best of our knowledge, the sample of women was the yet biggest achieved for an autonomous expedition in a Polar environment. Furthermore, a sled pulling expedition in complete autonomy in Antarctica has limitations for measurements; where the devices need to be light weight, possess a capacity to work at low temperature, easy to use by trained crew members, and quick and easy to take measurements. Still, the measurements also needed to be sent easily by internet or phone via satellite requiring less energy possible. These limitations affected the choice of measurements made during the expedition and could have affected the level of precision provided by the devices, the number of measurements taken and which parameters could be recorded as described in the methods section. Thus, It was not possible to have access to a DXA scan during the expedition (onboard the ship and the continent). We used a skinfold approach for body composition (ultrasound device in this study) that is not as precise as a DXA. The skinfold equation to estimate the % BF and the lean mass has a large error (Ball, Altena, and Swan 2004), but this error in our study was constant and allowed us to follow changes, even though the absolute % BF and lean masst could have been over or underestimated when compared to a DXA count. Nonetheless, the ultrasound device used in this study shows a better correlation with the DXA (r=0.98) in comparison to the bioelectrical impedance (r=0.92) and air displacement plethysmography (r=0.94) (Duz, Kocak, and Korkusuz 2009; Pineau, Guihard-Costa, Bocquet 2007; Pineau, Filliard, and Bocquet 2009) and no significant difference with skinfolds (Wagner 2013). Furthermore, the ultrasound is not affected by subcutaneous fat thickness; loose connective tissue and hydration level (Wagner 2013). Finally, many strategies were used during the expedition such as high-caloric diet, lighter and higher cold protection equipment. The absence of control group cannot allow us to observe the importance from each strategy in the success of the expedition.

Pulmonary function

The pulmonary function (FVC and FEV_1) were not affected by the expedition. The pulmonary function hypothesis was based on previous work, where the investigators observed an increased airway resistance, mostly caused by bronchoconstriction, following intense exercise at cold exposure. Acute cold exposure elicits several effects on the respiratory system (Giesbrecht 1995). A previous study observed a significant decrease of FEV_1 after exercise at cold exposure (Therminarias et al. 1998). Other studies observed airway obstruction, inflammation and hyperactivity in dogs, horses, and human athletes during routine exercise in cold conditions (Davis et al. 2001; Davis et al. 2002) and an important increase of asthma risks for outdoor workers exposed to cold environments (Kotaniemi-Syrjänen et al. 2003). Furthermore, long duration exposure to cold is associated with a greater susceptibility to respiratory infection and is based on complex interactions where mechanisms need to be clarified(Mourtzoukou and Falagas 2007). In the present study, however, the pulmonary function did not appear to be affected and was maintained possibly due to modern expedition clothing equipment during a month long ski sledge pulling excursion in Antarctica in the first quarter of the year.

Grip Strength

The present study did not observe a significant difference for grip strength before and after the ski sledge pulling excursion in Antarctica. The lack of change in grip strength indicates that there were no deleterious effects on neuromuscular function and is possibly due to the relatively short exposure time and/or the latest technology clothes. Previous studies have indicated that the sensation of pain decreases with repeated cold exposure, as the conduction velocity, but in conjunction with a vasoconstriction of hand blood vessels that may induce a performance decrease in grip strength (Cheung 2015). Other studies have shown that grip strength is maintained when manual handling tasks are repeated daily over several weeks' time in a routinely worked cold environment (Tochihara 2005). Thus, in the present study it is possible that daily tasks prevented grip strength deterioration despite the cold environment. As well, grip strength maintenance is an important aspect that supports the explorers in a cold environment, to complete vital expedition tasks that required grip strength for cooking, ice climbing, rescue crew members, etc.

Oral temperature

The oral temperature in the current study did not significantly decrease at cold exposure in contrast to other investigators that reported a significant drop in body temperature with different measurements (Mäkinen 2007; Stocks et al. 2004). The only significant difference observed (Fig. 4.2C) was between the last day of the sailing period towards Antarctica, and the end of the expedition on the Forbidden Plateau. This difference, however, is not a major concern due to the differences in the crew member environment (ship vs Forbidden Plateau) that are related to ambient temperature, seasickness influence, sleep quality, different tasks, but to name a few. A previous study (Case et al. 2006), however, has shown a decline in core temperature in human explorers exposed in hypothermic cold environment (Case et al. 2006; Mäkinen 2007; Stocks et al. 2004). Furthermore, as indicated in Table 4.1, the %BF at the end of the expedition was significantly lower, but was still within normal range(Frykman et al. 2003; Stroud 2001). Furthermore, the oral temperature in women did not change significantly and is possibly due to a lack of menses during the expedition. However, it was not possible to observe a significant difference in body temperature between sex, where in a previous study women had a lower rectal temperature than men even with amenorrhea(Graham et al. 1989). Finally, the oral temperature monitoring did not corroborate previous studies, possibly caused by today's better quality of clothing (Merino wool under garments) and equipment that allowed the explorers of the current study to be better protected from the cold and/or due to the small loss in %BF that contributed to maintain and prevent a decrease in body temperature during the sled-pulling excursion (Budd 1962; Case et al. 2006; Milan, Elsner, and Rodahl 1961).

Energy expenditure and body composition

The energy expenditure in Antarctica is often calculated, taking into account the progression over difficult terrain, using the weight of the equipment on the sled and the backpacks, the clothes weight, and thermoregulation (Campbell 1981; Simpson 2010; Teitlebaum and Goldman 1972) The progression in snow can increase the energy expenditure depending on the surface (soft snow, depression in the snow, etc.) and wind speed (Pandolf, Haisman, and Goldman 1976; Simpson 2010; Smolander et al. 1989)

The crew progression for this expedition was by ski-trek and sledge pulling, the energy expenditure was calculated by a simulation on a self-propelled treadmill and by using the Frykman et al. (2003) study where the wind, snow type, and plateau ascent (similar to the present expedition) was measured to estimate the energy requirements. The Frykman et al (2003) study shows that the lowest level measured was 14.7MJ/day for one of the subjects (around 82 kg weight), where the snow was hard, the wind was from behind, and the supplies in the sleds were half consumed, in comparison to the highest measurement of 34.6MJ/day for another subject (around 100 kg weight) during ascent to the plateau, with cold temperatures and deep snow soft, where it was difficult to pull the fully loaded sled. In their study (Frykman et al. 2003), the sled-pulling consisted as a submaximal exercise and could have been difficult to estimate exactly the impact of cold due to conflicting studies about energy expenditure during submaximal exercise exposed to cold, where many factors can intervene (Oksa et al. 2004; Poehlman, Gardner, and Goran 1990) . Several studies have reported no significant difference at submaximal exercise in cold temperatures (Jacobs, Romet, and Kerrigan-Brown 1985; Patton and Vogel 1984), whereas others have reported an increasing energy cost by 10%-40% for every decrease of 0.5-2.5 °C core temperature (Oksa et al. 2004; Pendergast 1988; Sandsund et al. 1998). This conflict can be probably due to different cold exposures and different clothing protection (clo) that can produce different core temperature changes during exercise (Oksa et al. 2004; Sandsund et al. 1998). Furthermore, no evidence suggests an adaptive response in heat production during chronic cold exposure (Poehlman, Gardner, and Goran 1990). Thus, in the present study, considering that the %body fat from the beginning to the end of the progression did not change significantly, the proposed diet appears to meet the requirement for energy expenditure by the team.

The weight of clothing can increase energy expenditure during an expedition, mostly when the clothing strategy is to use layers, where the energy expenditure was 16% higher with the layered arctic clothing than the same weight on a belt (Teitlebaum and Goldman 1972). This can be important if we consider that the clothing weight for Antarctica explorers in a previous study was 11.9 kg (Teitlebaum and Goldman 1972). Nonetheless, during the present study the clothing weight suggesting less energy expenditure attributed to clothing weight technology (~6 kg), and better protection from the cold temperature by new technology such as wind-stopper (Mammoth, Gore-Tex, CH) and merino wool. In addition, no cold injuries were reported and/or diagnosed during and after the expedition. The present study observed no significant difference in the body composition pre- vs. post-expedition with the latest technology (clothing, sleds, rucksacks, food, etc.) where the contribution of lighter equipment and food weight with a possibly greater caloric intake had an impact on the success of the present expedition.

Cognitive performance, mood scale and effort perception

In previous studies reaction time decrease with cold exposure, exposing explorers to increased risks (Frykman et al. 2003; Halsey and Stroud 2012). This impairment to cognition and psychomotor performance increases the risk when decision making needs to be done quickly, like falling in a crevasse or other dangers during advancement in an expedition, which can affect emotions by the perception of success in the expedition. Furthermore, the crew dynamic in isolation environment, even with virtual communications, can have influence on cognitive performance and emotions(Kanas et al. 2009). The present study did not find any significant differences in reaction time and emotions perception. The maintain of cognitive performance and emotion perception can be influenced by a focus to the present moment, focused on everything, both positive and negative even after long duration exposure to cold and the high perception effort that was significantly higher at the end of the expedition. According Block-Lerner et al. (Block-Lerner et al. 2007) mindfulness is the overall nonjudgmental/acceptance of the present-moment of one's own emotions, positive and negative. The present-moment awareness or mindfulness is characterized by a focus on the present experience, the regulation of the attention and consciousness (Brown and Ryan 2004). During the present-moment, the explorer can be more aware of positive and negative emotions. However, this hypothesis needs to be tested in future studies with mindfulness tools like the Philadelphia Mindfulness scale (Cardaciotto et al. 2008).It is possible that the crew used this technique to make the decisions and be able to continue the expedition even if the stress and the effort perception increased significantly(Simpson and French 2006) . Therefore, the Mood scale results did not show the results that were expected, that positive emotions would decrease with the time of the expedition due to the challenges the crew had to face and inversely for the negative emotions. The PANAS shows positive (PA) and negative (NA) emotions and they should be incompatible, however they are *relatively* independent when they are at opposite poles of the same dimension (Crawford and

Henry 2004). Crawford and Henry (2004) explained that the relationship between the PA and NA are small to moderately correlated (r between -.43 and -31). However, the PANAS can be an important tool, in a short time frame, to detect anxiety and depression by adequate psychometric properties in a large sample of adult population(Crawford and Henry 2004) . Finally, the OMNI scale shows the increasing effort perception during the ski sledge pulling trekking excursion with a significant difference observed pre vs post the trekking excursion. That result was expected and corroborated with previous studies about ski expedition where the effort perception increases, probably due to the cumulative fatigue as seen in previous studies(Frykman et al. 2003; Stroud 2001) .

Cortisol and Stress influence

The salivary cortisol did not change significantly during the expedition. However, even if punctual cortisol via saliva was not significantly different pre vs post expedition, the hair cortisol, representing general stress, was significantly higher during the expedition than the month previous the expedition measurement. The cortisol is an important marker for the immune system and the response to stress (Yadav et al. 2012) and is affected by circadian rhythm. Previous studies observed the impact of light cortisol levels in the polar environment on the workers given that the amount of daylight varies a lot at the poles (Harris and Waage 2011). However, the cortisol does not seem to be analyzed for short period expeditions like in the present study, where the amount of daylight has a minimal impact given that it is close to the "normal days" of around 12h of daylight. In a previous study (Yadav et al. 2012), where the cortisol was analyzed during the winter, March to November, the cortisol level were significantly increased during March to August and decreased in November. In the current study, the excursion was during February and March. However, it is not possible to know if it is due to altered circadian biorhythms, extreme cold exposure, radiation exposure, or other factors. Furthermore, Bishop and al. (2001) compared the stress factor such as cortisol from the leader compared to the crew members at the camp during an Arctic ski expedition. The authors stated that no conclusion can be drawn by their data from a small sample, but needed to be studied further for a better understanding of the leader challenges during an expedition. Nonetheless, the present study corroborates some results from Bishop and al. (2001), where the leader position seemed to have an important impact on the stress level, where an important increase, at least greater than the other crew members, the % saliva cortisol increased on the first day of the expedition. However, these data are only on one person and no conclusion can be drawn with these data. The present study tried to observe this interaction further, however the variability was high, and nothing significant could be observed with our measurements. In summary, the hair sample observed a significant increase of the stress marker cortisol for the month long expedition compared to the month before the expedition. However, no significant difference was observed with punctual points of view via saliva cortisol. These data corroborate the importance to investigate further the stress impact of expedition as presented by Kanas et al. (2009) to propose tools and preparation for explorer in the future.

Recommendations

Monitoring explorers can be useful to provide assistance at a distance, but also contribute to a better understanding of physiological and cognitive changes during an expedition. The different measurements taken during the expedition were captured on a tough pad portable tablet (powered by solar panels) where it was possible to transmit the results by internet when available. However, internet satellite communication access in Antarctica is difficult and is disrupted by mountains/peaks, snow storms, etc. Despite these challenges, it was relatively easy to transmit physiological and cognitive measurements during the present expedition. Tele-monitoring for physiological and cognitive variations can help remotely based specialists, i.e., the ship based team in the present study, and if needed, a medical team based in Montreal, to provide assistance to the explorers when confronted with complications, such as illness, mental health support, geographical orientation, weather reports, etc. Undoubtedly, with the advancement of technology it is now possible to improve the present set-up for telemedicine support and measure the impact of new equipment/technologies and preparation for future explorers. This pilot-project provided novel simple fast obtained measurements that can be used during an expedition without added weight and device training for the explorers. Time is of the essence and devices that are light, quick and easy to use are crucial during a sled-pulling excursion in complete autonomy with non-scientific crew members. Nevertheless, many improvements are required to increase the quantity and the quality of information about crew health, such as ECG, arterial hemoglobin oxygen saturation and pulmonary ventilation (V_E) during the excursion.

4.3.7. Conclusion

Physiological, body composition and cognitive monitoring in this study shows that the general stress during the expedition was significantly higher than the month prior to the expedition (hair cortisol), suggesting that a month long ski sled pulling excursion is somewhat stressful. Nonetheless, indicating that the increased level of stress was perhaps necessary to maintain alertness without being deleterious to other body functions. In fact, this apparent increase in stress did not have an impact on respiratory function, oral temperature, body composition and, grip strength. Furthermore, maintenance of lean mass can be observed with a high caloric intake during an expedition in Antarctica. This is,, with the latest technology and physiological preparation, possible keys countermeasure to prevent lean mass and physiological capacities loss in an extreme environment

Future research, however, is needed to learn more about other physiological parameters, such as ECG, EEG, ventilation, saturation, and psychological responses in an extreme environment that can be used as a telemedicine tools and eventually benefit citizens in remote areas. Also, future projects with a larger sample size of both women and me are needed to gather a more accurate understanding of physiological and cognitive responses in humans, but also for a better understanding of sex differences.

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4.3.9. References

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Figures

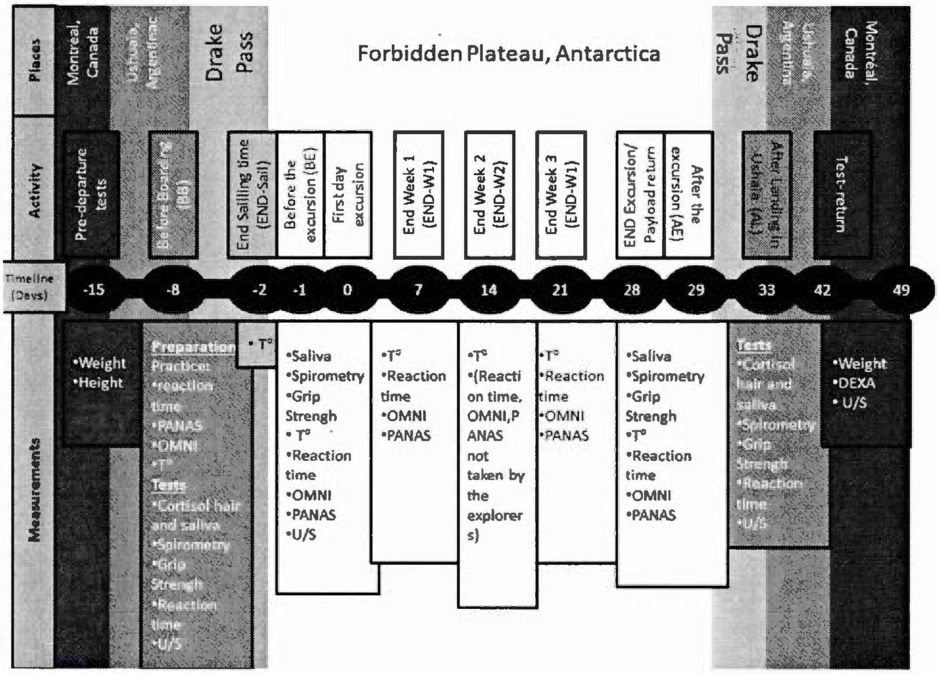

Figure 4.1:Timeline of the expedition and the measurements; T°: oral temperature; U/S: ultrasound

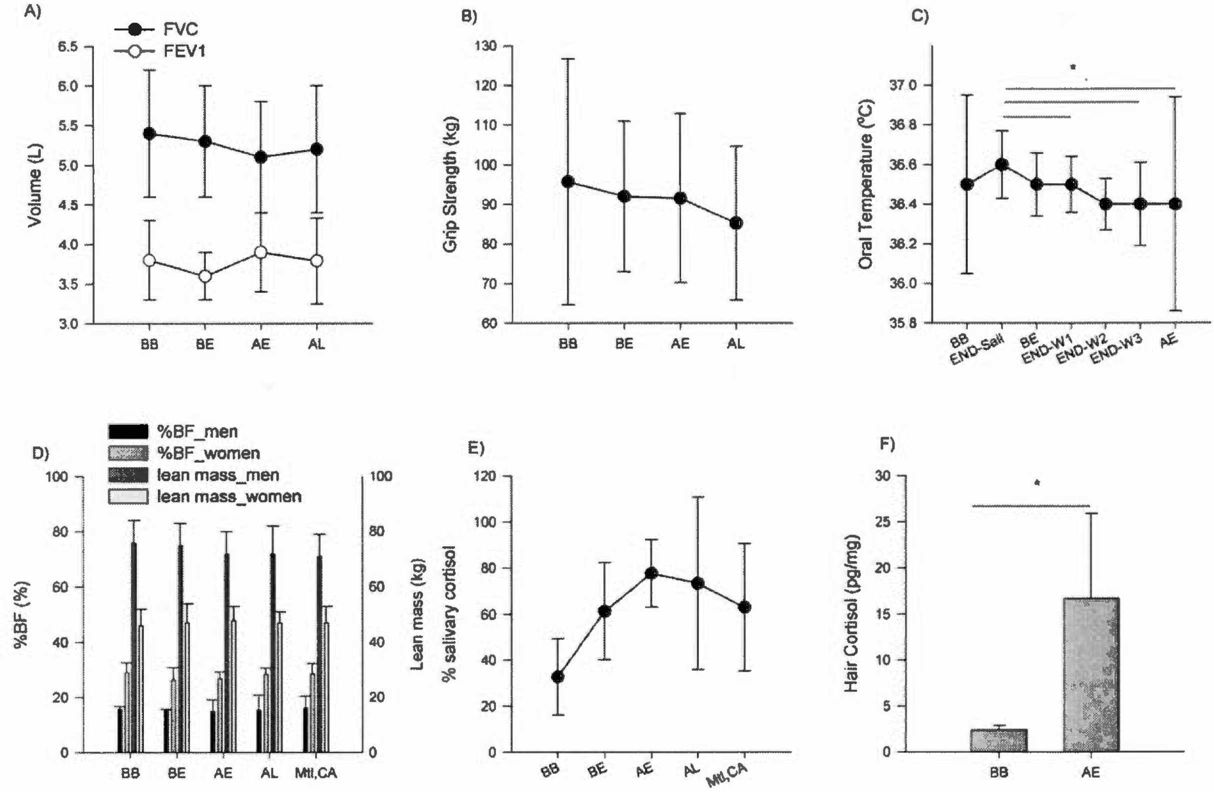

Figure 4. 2:Physiological measurements during the expedition. A) Relationship between spirometry and time B) Relationship between grip strength and time C) Relationship between oral temperature and time D) Relationship between percentage of body composition and time by sex Relationship between salivary cortisol and time E) Relationship between hair cortisol and time, where BB: Before Boarding to Antarctica, END-Sail: last day of sailing to Antarctica, BE: Before ski-trekking Excursion, END-W1: last day of the week 1, END-W2: last day of the week 2, END-W3: last day of the week 3, AE: After ski-trekking Excursion, AL: After landing in Ushaïa, Mtl,Ca: at return in Montreal, Canada; %BF: percentage of body fat; *:p≤0.05

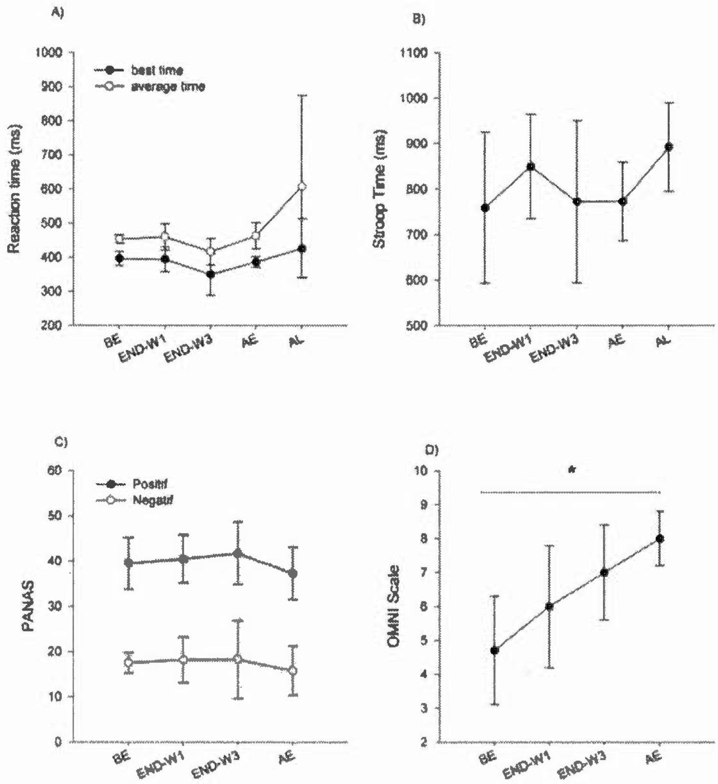

Figure 4. 3:Cognitive measurements during the expeditionA) Relationship between reaction time best and average and time B) Relationship between the Stroop test total time and time C) Relationship between Mood Scale by PANAS questionnaire and Time and, D) Relationship between the effort perception on the OMNI scale and time;*:p≤0.05

4.3.10. Tables

Table 4.1:Physiological values for women, men and group

	Before Boarding			Before expedition			After Expedition			After Landing		
Variables	Women	Men	Group	Women	Men	Group	Women	Men	Group	Women	Men	Group
GS (kg)	60.0±13.9	122.3±9.1	95.7±31.0	78.0±12.3	106.0±13.1	92.0±19.1	75.7±12.4	107.3±15.0	91.5±21.3	71.0±14.1	99.3±11.8	85.2±19.4 (0.09,n^2_p=0.548)
FVC (L)ǂ	4.5±0.1	6.0±0.3	5.4±0.8	4.5±0.4	5.8±0.2	5.3±0.7	4.3±0.1	5.6±0.2	5.1±0.7	4.4±0.1	5.7±0.3	5.2±0.8 (0.32,n^2=0.310)
FEV1 (L)ǂ	3.5±0.1	4.4±0.2	3.8±0.5	3.3±0.1	4.38±0.05	3.7±0.6	3.6±0.3	4.4±0.4	3.9±0.5	3.4±0.04	4.39±0.02	3.79±0.54 (0.99,n^2_p<0.001)
FEV1/FVC (%)ǂ	77.5±1.1	73.1±8.7	75.3±5.7	75.7±7.1	74.4±1.7	75.1±4.3	78.9±0.2	80.0±4.6	79.4±2.7	77.5±2.1	68.4±13.4	72.9±9.4 (0.67,n^2_p=0.104)
SC (%)	34.5±11.7	50.3±40.5	42.4±28.0	62.1±20.0	57.0±22.6	59.5±19.3	72.8±33.5	70.3±41.5	71.6±33.8	59.8±29.2	73.3±27.4	66.6±26.4 (0.09,n^2_p=0.547)
T° (°C)	36.4±0.7	36.5±0.2	36.5±0.5	36.5±0.2	36.4±0.2	36.5±0.2	36.5±0.2	36.2±0.2	36.4±0.2	36.3±0.8	36.5±0.2	36.4±0.5 (0.25,n^2_p=0.310)

*Mean±SD (p,ES); * p 0.05; GS: Grip Strengh; SC: saliva cortisol; T°: oral temperature; FVC:forced vital capacity;FEV1: Forced expiratory volume in 1 second, ǂ: n=5 due to a problem with the device*

CHAPITRE V: NOUVEL APPAREIL DE TÉLÉMÉDECINE PERMETTANT DE SUIVRE UNE ÉQUIPE EN EXPÉDITION

5.1. Mise en contexte

Il a été indiqué au dernier chapitre que les solutions en télémédecine peuvent être limitées. Toutefois, les nouvelles technologies nous permettent de prendre un plus grand nombre de données tout en respectant les contraintes de l'expédition. Cette technologie, l'Astroskin, une veste intelligente permettant de mesurer entre autres les fréquences cardiaques, les fréquences respiratoires et la température cutanée au niveau supra iliaque a été testées durant l'expédition afin de suivre l'équipe et de proposer des solutions pour prévenir les blessures et la surcharge où les données de signes vitaux peuvent être transmises via satellite. Cette nouvelle technologie de télémédecine a été testée seulement sur 4 explorateurs où malheureusement une veste a cessé de fonctionner dès le début de l'expédition. Toutefois, cette technologie prometteuse pourrait aider plusieurs futurs explorateurs en milieu extrême, mais également pourrait être utilisée dans des milieux de travail extrême comme les pompiers, les miniers dans les super-mines et dans le milieu dans la santé en réadaptation, particulièrement pour les personnes en région éloignée.

5.2. Résumé

Les expéditions en Antarctique sont physiologiquement difficiles qui peuvent parfois avoir des conséquences fatales. L'objectif global de cette étude était de proposer de nouvelles stratégies de survies par télémédecine. L'objectif spécifique était d'observer les paramètres physiologiques d'explorateurs pendant 30 jours durant une expédition en complète autonomie en Antarctique. Une équipe de 3 explorateurs (2 hommes et 1 femme) ont été suivis en continu à l'aide d'un vêtement intelligent où la fréquence

cardiaque (FC), la fréquence respiratoire (FR) ont été mesurées et où la réserve de fréquence cardiaque (FCR) a été calculée. En outre, la température orale a été prise avant l'expédition, au premier jour, à la fin de la première semaine, aux derniers jours de la progression sur le Forbidden plateau en Antarctique. Le cortisol salivaire a également été pris avant l'expédition, au premier et au dernier jour de l'expédition. L'analyse statistique Friedman a été utilisée pour comparer les mesures. Les résultats des différents paramètres sont présentés en moyenne ± écart type. Aucune différence significative n'a été observée au niveau des paramètres physiologiques pour les mesures du premier jour, de la fin de la première semaine, des derniers jours de l'expédition et de la mesure pré-expédition pour la température orale (36,4 ± 0,6 ° C, 36,4 ± 0,1 ° C, 36,4 ± 0,2 ° C, 36,7 ± 0,3 ° C respectivement, Chi-Square = 3,889, p = 0,274), la température de la peau (34,3 ± 0,6 ° C, 33,8 ± 0,9 ° C, 34,6 ± 1,5 ° C, 36,0 ± 1,4 ° C respectivement, Chi-Square = 3,6, p = 0,308), FCrepos (86 ± 3bpm, 88 ± 5bpm, 84 ± 10bpm, 77 ± 6bpm, respectivement, Chi-Square = 2,172, p = 0,537) et le cortisol (94,4 ± 10,9%, 89,2 ± 26%, 46,3 ± 41,1% pour le premier jour et le dernier jour de l'expédition, et la mesure pré-expédition respectivement, Chi-Square = 3,889, p = 0,274). La charge de travail au cours des premiers jours était supérieure à 50% le la FCR pendant plus de 6 heures, classées comme un travail difficile en continu. Toutefois, le temps à cette intensité a diminué au cours de l'expédition. Cependant, l'intensité via la FC était semblable (177 ± 5 bpm le premier jour VS. 165 ± 3 bpm à la fin de la première semaine VS. 174 ± 30 aux derniers jours, Chi-Square = 2.000, p = 3.68), où la moyenne des FR était de 27,9 ± 2,9 h / min le premier jour. En conclusion, il semble que les explorateurs avaient une importante charge de travail au cours de l'expédition, mais le temps en haute intensité a diminué durant l'expédition pour réduire le risque de «surcharge» et de blessure. L'exposition au froid n'a pas semblé avoir un impact sur la température orale et l'anxiété durant l'expédition sur la sécrétion de cortisol pendant l'expédition. Cependant, une étude plus poussée avec un échantillon plus important et une analyse de la variabilité du rythme cardiaque devra être effectuée pour observer l'impact possible du stress par le froid, de l'anxiété et du sommeil pendant une expédition polaire. Ainsi, les mesures de la veste intelligentes sont non invasives et semblent être un bon outil pour télémesurer les explorateurs pendant un voyage prolongé afin de prévenir le risque de surcharge et de risque de blessure.

5.3. Article

5.3.1. Cardiorespiratory Responses during a 30 days Expedition in Complete Autonomy in Antarctica. A Case report (IAC-16-A1-IP(32147)

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5.3.2. Abstract

Antarctica expeditions are physiologically challenging and include possible fatalities. The overall goal was to propose new strategies for telemedicine monitoring. The specific objective was to monitor physiological parameters of explorers during 30 days complete autonomous expedition in Antarctica. A crew of 3 explorers (2 men and 1 women) were monitored continuously with an intelligent garment for heart rate (HR), breathing frequency (BF), where the Heart Rate Reserve (HRR) was calculated . Furthermore, the oral temperature was taken at baseline, the first day, end of first week, last days of the expedition progression on the Forbidden Plateau in Antarctica and the salivary cortisol was taken at baseline, the first and last day of the expedition. Friedman was used to comparing the measurements. The different parameters results are presented in mean ± standard deviation form. No significant differences were observed over time within the physiological parameters for measurements at the first day, end of first week, the last days of the expedition, and the baseline for the oral temperature (36.4±0.6°C, 36.4±0.1°C, 36.4±0.2°C, 36.7±0.3°C respectively, x^2= 3.889,p=0.274), the skin temperature (34.3±0.6°C, 33.8±0.9°C, 34.6±1.5°C, 36.0±1.4°C respectively, x^2= 3.6,p=0.308), HRrest (86±3bpm, 88±5bpm, 84±10bpm., 77±6bpm, respectively, x^2 2.172, p=0.537), and the cortisol (94.4±10.9%, 89.2±26%, 46.3±41.1%.for the first day and the last day of the expedition, and the baseline respectively, Chi-Square= 3.889,p=0.274) . The workload during the first days was over the 50% HRR for more than 6 hours, classified as a hard continuous work, but the amount of time at this intensity decreased later on the expedition. However, the HR peak reach was similar (177±5 bpm the first day VS 165±3 bpm at the end of the first week VS 174±30 at the last days, x^2=2.000, p=3.68.), where the BF average was 27.9±2.9 breath/min the first day. In conclusion, it appears that explorers important workload during the expedition, but the time at in high intensity decreased with the

expedition to reduce the risk of "overload" and injury. Cold exposure did not appear to impact the oral temperature and the expedition anxiety on the cortisol secretion during the expedition. However, further investigation with a bigger sample and heart rate variability analysis will need to be done to observe the possible impact of cold stress, anxiety and sleep during a polar expedition. Thus, non-invasive furtive intelligent measures appear to be a good tool to telemonitor explorers during a prolonged journey to prevent the risk of overload and injury risk.

Keywords: Antarctica Expedition, Heart rate, Heart Rate Reserve, workload, telemonitoring

Acronyms/Abbreviations

Battements par minute (bpm), Breathing Frequency (BF), Heart Rate (HR), Heart Rate Reserve (HRR).

5.3.3. Introduction

Ambient temperature can be a stressful situation on the human body. The exposure to cold induces many physiological responses such as increases resting metabolism, marked peripheral vasoconstriction, reduced heart rate, increase in blood pressure and increase in cardiorespiratory strain(Cheung, Lee, and Oksa 2016; Doubt 1991; Stocks et al. 2004). Cold acclimatization and habituation mechanisms are subjects of controversy in the literature (Cheung, Lee, and Oksa 2016; Makinen 2010;

Muller et al. 2014; Wyndham, Plotkin, and Munro 1964). Furthermore, prolonged cold exposure, hours to several days, seems to amount in the literature to various, sometimes opposing conclusions, on the physiological responses such as manual dexterity (Muller et al. 2014). However, authors seem to agree that at exercise, the regional heat flux increases proportionally to the intensity of the workload and the muscle blood flow (Doubt 1991; Makinen 2010). Besides, the perception of pain and discomfort induced by cold appears earlier at the same intensity than at ambient temperature, apart when cold acclimatisation has occurred (Doubt 1991; Makinen 2010).

All of the above mentioned physiological responses increase the risk of task failure during extreme cold exposure and can have fatal consequences during expeditions. The stress induced in polar expeditions include many aspects such as high metabolism needs, and both physical and psychological stress in response to danger (Buguet, Cespuglio, and Radomski 1998; Lieberman, Castellani, and Young 2009). These different types of stress have many impacts on the cardiorespiratory system, but also on different systems like the immune system, neurological response and hormonal, where the synergy between the systems play a role in the physiological responses (Doubt 1991; Makinen 2010). Nonetheless, even if the crew is physically prepared and can communicate with a rescue team, monitoring a team to track the workload and reduce the risk.

The Heart Rate Reserve (HRR) is used to measure the workload in the area of work physiology. This measure can help to prevent overload and injury risk. Thus, the purpose of this study was to observe with a new telemedicine device the workload and sleep of a crew in a cold environment expedition. Furthermore, the oral temperature and salivary cortisol was measured during a 30 day expedition in Antarctica on the anxiety and possible oral temperature changes due to chronic cold exposure.

5.3.4. *Material and methods*

2.1 Participants

The crew was composed of 3 explorers (2 men and 1 women; 26 ± 5 years old). All crew members had experience in ice climbing and expedition. The physical preparation of the crew included a pre-expedition field trip, in the Columbia Icefield (Canadian Rockies), 2 months before departure to Antarctica. That allowed assessment of field techniques and equipment, physical preparation and psychological challenges.

The study was approved by the Ethical Research with Human Committee from Science Faculty.

2.2 Heart Rate measurements pre-post-expedition

The pre and post expedition aerobic tests were conducted at the Human Performance laboratory (University of Quebec in Montreal). The tests were scheduled one week before the flight to Argentina where the boat to Antarctica would be boarded and one week after the return of the crew to Montreal. The Heart Rate at rest was taken in complete silence in sitting position for at least 5 minutes without talking.

Participant took part in a sub-maximal test at an ambient controlled temperature (20 ± 1°C) and at a cold temperature (-1 ± 8 °C). The participant acclimatised to the cold temperature environment for approximately 30 minutes before beginning the sub-maximal test. The sub-maximal test consisted of a single step step-test Cardiorespiratory parameters (HR and VO2) were measured with a portable metabolic analyser (K4b2,Cosmed, It). The comparison between the HR at the ambient temperature and the HR at the cold temperature was calculated by subtracting the HR ambient response to HR cold response (△ctl-cold) at the end of the sub-maximal test. The moment choice was in function to reproduce, as close as possible, the expedition situation.

2.3. Expedition conditions

The Antarctic expedition was included 3 parts: 1) sailing across the Drake pass (~1700 km sea travel), 2) followed by skiing progression 30 days expedition in Antarctica on the Forbidden plateau in complete autonomy and 3) ended by sailing return across the Drake pass. The typical progression was constituted of skiing progression, pulling an equipment-laden sledge of approximately 70 kg and backpacks (initially 30 kg), on an average of 10-15 hours/day.The weather conditions were mostly temperatures around -20 to 40°C , with wind and whiteout. The approximate average altitude on the Forbidden Plateau was at 1500 m.

The HR, BF and supra-iliac skin temperature were measured with the Astroskin, an intelligent garment developed for the Canadien Space Agency, by Carre Technology. The garment recorded during 24h every 2 to 4 days depending of the possibility to recharged the batteries with solar panels. The oral temperature was taken in the morning without contact to the exterior environment in a tent to control the wind effect on ambient temperature. Also, no food nor beverages were consumed 6h previous to the measurements as indicated in the guidelines (Sermet-Gaudelus, Chadelat, and Lenoir 2005). The cortisol was taken and kept frozen for analysis in Montreal. The HR at rest during the expedition was measured when the explorers were in a sitting position for at least 5 minutes in the tent. Baseline measurements were taken one week prior to the expedition during their preparation in Ushuaia, Argentina.

The cortisol measurement was made the morning according to the guidelines (Aardal and Holm 1995; Kirschbaum and Hellhammer 2000). The results are presented in function of the reference table as a function of age, sex and moment of the day as presented by Aardal and Holm 1995 (Aardal and Holm 1995).

2.4. Statistical Analysis

All values are reported as mean ± S.D. The pre and post expedition results were compared using Wilcoxon (analysed pre-post) and Friedman (analysed baseline, first day, end of the first week and last days of the expedition) due to the sample size. Significance was set at the 0.05 level. The statistic analysis was performed with SPSS Statistic 20.

5.3.5. Theory and calculation

The following equations were used to present the results taking into account the physiological individual variances.

3.1 Heart Rate Reserve

Measurements and calculation physiological workload by the Relative heart rate at work, Heart Rate Reserve (%HRR), was according to previous studies (Çalişkan and Çağlar 2010; Gatti, Schneider, and Migliaccio 2014; Umberto Gatti et al. 2014) with the following equation:

$$\%HRR=(HRwork-HRrest)/(HRmax-HRrest)X100 \quad (1)$$

where HRwork is the heart rate during the activity, HRrest is the heart rate at rest and HRmax is the maximum heart rate during a maximal aerobic test.

5.3.6. *Results*

The participants' characteristics and the cardiorespiratory measurements took in Montreal are shown in Table 5.1. No significant difference was observed between the different parameters.

The HR and a sample of the breathing frequency (BF) for the first day of the expedition in Antarctica are shown in fig. 5.2. The HR during the haft duration and the last day of the expedition are shown at the fig 5.3 A and B. The HR and skin temperature during sleep during the end of the first week of the expedition is shown at figure 5.3 C and temperature and rest measurements during the expedition compared to the baseline is shown in the figure 5.3 D. The measurements at the first day, end of the first week, the last days of the expedition, and the baseline for the oral temperature (36.4±0.6°C, 36.4±0.1°C, 36.4±0.2°C, 36.7±0.3°C respectively, x^2e= 3.889,p=0.274), the skin temperature (34.3±0.6°C, 33.8±0.9°C, 34.6±1.5°C, 36.0±1.4°C respectively, x^2= 3.6,p=0.308), HRrest (86±3 b.p.m., 88±5 b.p.m., 84±10 b.p.m., 77±6 b.p.m. respectively, x^2= 2.172,p=0.537), and the cortisol (94.4±10.9%, 89.2±26%, 46.3±41.1%.for the first day and the last day of the expedition, and the baseline respectively, x^2= 3.889,p=0.274) was not significantly different during the expedition, and in comparison to the baseline. Furthermore, the HR peak reach was not significantly different (177±5 bpm the first day VS 165±3 bpm at the end of the first week VS 174±30 at the last days, ,x^2=2.000, p=3.68.), where the BF average was 27.9±2.9 breaths/min the first day

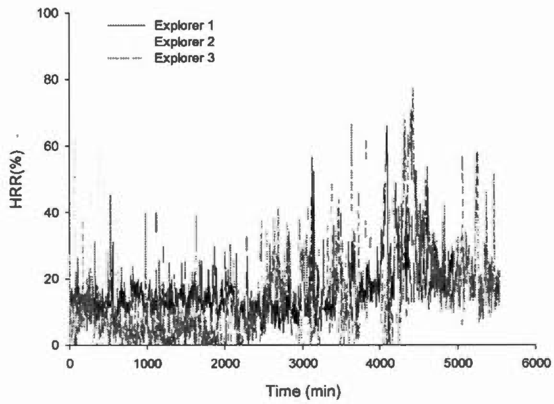

Figure 5. 1: Heart Rate Reserve (HRR) during the baseline

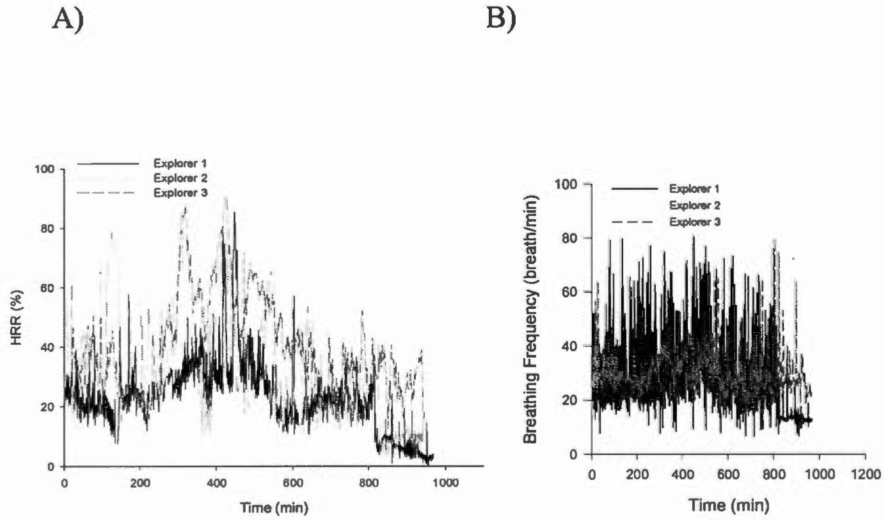

Figure 5.2 : A) Heart Rate Reserve (HRR) during the first day of progression in Antarctica B) Breathing Frequency (BF) during the first day of progression in Antarctica

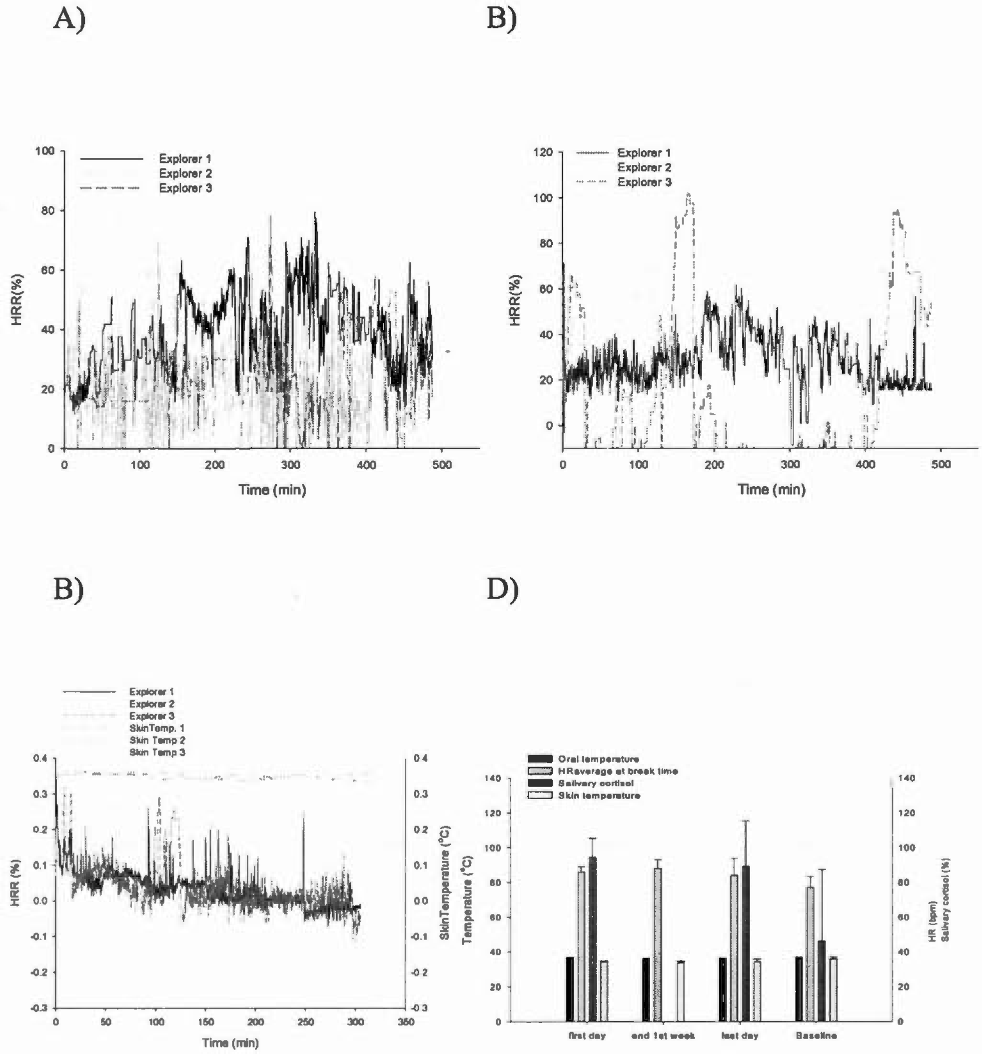

Figure 5. 2: A) Heart Rate Reserve (HRR) at the end of the first week of the progression in Antarctica B) Heart Rate Reserve (HRR) at the last days of the progression in Antarctica C) Heart Rate Reserve (HRR) and skin temperature during sleep at the end of the first week in Antarctica D) HR, Oral temperature and cortisol at the first day, end of the first week and last days of the expedition in Antarctica.

Table 5.1Explorers' characteristics

	Pre-Expedition		Post-Expedition		Statistic	
	Mean	SD	Mean	SD	Z	p
Age (year)	26	5				
Weight (kg)	80.0	14.9	76.9	11.0	-1.069	0.285
Height (cm)	183.4	3.2				
HR rest (bpm)	64	11				
HRmax (bpm)	197	5				
△HRcontrol temp-cold pre	5.4	4.0	9.3	1.5	-1.069	0.285

5.3.7. *Discussion*

The main finding of this study was that during the expedition the crew did not appear to be exposed to cold at a point where physiological changes may occur like shown in previous studies (Makinen 2010).This may possibly be due to the equipment used by the crew (tent, coat...). Previous studies have shown a significant difference in the stress response during cooling, where the response was reduced accompanied by an increase in skin temperature with cold exposition and a decreased rectal temperature (Makinen 2010). The present study did not observe physiological response changes. However, the sample was small (n=3) and seemed to show a trend where the cooling seemed to increase with HR being lower with cold and accompanied with a higher cortisol secretion during the expedition when compared to baseline. Furthermore, a previous study observed that individual physical characteristics play an important role on the thermal responses and acclimatisation to cold (Makinen 2010).

The HR and BF monitoring can be an important measurements to follow the workload of the crew during an expedition and some associated stress factors (U. C. Gatti, Schneider, and Migliaccio 2014; Vrijkotte, van Doornen, and de Geus 2000; Wu and Wang 2002) . The workload calculated using the %HRR is a validat technic and common in the area of work ergonomy (Çalişkan and Çağlar 2010; Gatti et al. 2014). The workload measured with %HRR allows to observe the physical strain and classify the injury risk "overtraining", exhaustion, stress fracture, error risk induce by fatigue...) in function of time at different intensities (Wu and Wang 2002). A %HRR over 50% is classified as a hard continuous work. The first day during the expedition the %HRR was above 50% for more than 6 hours. It is possible to observe this high intensity also with an augmentation of the BF, representing a high workload that is in close relation with the physical demand (Gatti et al. 2014; Haskell, Lee, Pate, Powell, Blair, Franklin, MacEra, et al. 2007). However, the BF is not a strong predictor of the workload as %HRR (Gatti et al. 2014) . It is for this reason that the %HRR was prioritised in the present study. The first day of the expedition required the ascent to the Forbidden Plateau, with the food weight and equipment. A similar peak level of exercise intensity was observed during a Greenland expedition in similar conditions (Frykman et al. 2003). In the current study, at the end of the first week and on the last days, the high intensity was a lesser period of time than the first day. It is important to notice that explorer 3 began to be sick during the expedition and explains the resting time during the last days. The Explorer 2 was with him on the rope team, but the explorer 1 was in another rope to scout the road.

Furthermore, exposition to cold disturbs sleep (Haskell, E.H. et al. 1981) and on a long term can change sleep patterns (Natani, K. et al. 1970). Moreover, an expedition can induce environmental and psychological stress and anxiety that can have an important impact on the HR (Buguet, Cespuglio, and Radomski 1998). Anxiety is known (Åstrand et al. 2003; Nicholson and Stone 1982) to disturb sleep or alertness and total sleep time is shorter, where similar HR curves from the present study are comparable to those of a worried pilot (Åstrand et al. 2003). The curves show an HR reactivity affected by mental state showing a longer duration from the time to go to bed to a "stabilisation" of the heart rate. However, more investigations need to be done with analysis including heart rate variability (HRV) and stage of sleep to obtain a better observation of the anxiety and environmental stress impact during sleep. The environmental stress can play an important role in the Very Low Frequency (VLF) component of the spectral HRV analysis and may offer information on the impact of this environmental parameter during sleep. In the present study, the skin temperature was the only measurement possible. This temperature was extremely variable and affected by the ambient temperature, the intensity of the effort and clothing. However, the skin temperature seems to play an important role in the sleep onset, where a skin warming can induce sleep onset when the core temperature does not change (Raymann, Swaab, and Van Someren 2007). In a cold environment, with the cold ambient temperature and the vasoconstriction response to cold, the skin warming can be affected and needs to be taken into consideration in the sleep quality of the crew. In the present study, the crew seemed to be able to keep an adequate warm temperature during the night and possibly prolonged sleep time like showed at figure

5.2 C. Finally, a bigger sample and further analysis of HRV will need to be done to observe the anxiety and the environmental stress impact (cold, altitude, humidity...). The observation of these aspects can be reduced when the measurement is taken only during the morning (measurement of oral temperature and rest HR). Where in the present study was not significantly different for the 3 moments analysed, but measurements during the day and more often would possibly show changes (fig. 5.3-2 D).

5.3.8. Space Application and Conclusions

Monitoring HR and BF can help to follow the workload of a crew in an extreme environment, but also seems to show some trends associated to anxiety moments or during sickness by the crew members. The new intelligent garment can be extremely useful for exploration in space, but also as a spin-off for workers like fishers, miners, forest workers or construction workers with important environmental constraints (heat or cold) and for explorers on Earth.

5.3.9. Acknowledgements

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CHAPITRE VI: LA TECHNOLOGIE PEUT AIDER NON SEULEMENT LES EXPLORATEURS

6.1. Mise en contexte

L'utilisation de nouvelles technologies afin de suivre des signes vitaux et progressions à distance n'est pas seulement vitale pour les explorateurs en milieu extrême, mais également dans le milieu de la santé. Par exemple, dans un contexte de réadaptations à la maison. Ce type de technologie pourrait être grandement avantageux, permettant un accès à un plus grand nombre de personnes, réduisant certaines limites dont le transport ou la contrainte de temps vécue par les patients. Toutefois, cette technologie se doit d'être abordable et accessible.

Plusieurs technologies abordables font leur place dans le marché grand public afin de suivre certaines données physiologiques comme les fréquences cardiaques (cardiofréquencemètre), la saturation de l'hémoglobine à l'oxygène (saturomètre), la qualité du sommeil et la dépense énergétique. Ces petits appareils permettent parfois de recueillir les données de qualités et ainsi permettre de faire un suivi à distance d'un patient. Parmi les technologies accessibles, les jeux vidéo actifs permettent d'offrir une modalité d'activité physique à la maison tout en ayant un certain nombre d'informations sur l'intensité et la fréquence de cette activité par semaine. Ce type de jeux jumelés à un appareil comme un cardiofréquencemètre pourrait devenir une solution afin d'offrir un programme de réadaptation à la maison. Toutefois, ces jeux doivent être d'abord testés par des personnes n'ayant pas de limitations à l'activité physique, mais néanmoins inactive, afin de mesurer les réponses physiologiques durant l'exécution de tels jeux et de tester cette solution. Des personnes inactives peuvent bénéficier de ce type de recherche en proposant un nouveau mode d'activité physique accessible tout en étant sécuritaires et possiblement ludiques pour eux. Il a d'ailleurs été proposé que les jeux vidéo actifs ne puissent pas rencontrer l'intensité d'activité physique minimum recommandée par l'ACSM où toutefois cela permettait un supplément ludique à un entraînement traditionnel (Biddiss and Irwin 2010). Néanmoins, plusieurs études antérieures ne prenaient pas en compte les concepts de mécaniques de jeux primordiales au choix devant être faits lors de la prescription de jeux vidéo actifs reliés à une pratique d'activité physique. Le présent chapitre présente une comparaison de type de jeux et de consoles afin de proposer un moyen de faire un choix plus averti face à la prescription de jeux vidéo actifs à des fins de pratiques de l'activité physique rencontrant les normes de l'ACSM.

6.2. Résumé

Les différents jeux vidéo actifs permettent une activité physique accessible et ludique, à condition qu'ils soient suffisamment intenses et motivants. Cependant, peu d'études s'intéressent à déterminer quels sont les consoles et les types de jeux vidéo actifs permettant une intensité d'activité physique pour répondre aux normes de l'American College of Sports Medicine (ACSM). **Méthode***:* Un total de 10 joueurs masculins inactifs (âgés de 26 ± 5 ans), ont été recrutés pour mesurer la dépense énergétique requise par trois types de jeux sur différentes consoles. Les consoles suivantes ont été sélectionnées: PlaystationMove et Kinect, et trois catégories de jeux: danse (Just Dance 3,), entraînement avec un entraîneur (MiCoach) et action (Star Wars pour Kinect et No More Heroes pour PSMove). **Résultats**: Les METs moyennes et maximales (moyenne ± écart-type) à la fois sur Kinect vs PlayStationMove, respectivement: JustDance, 6,87 ± 1,26 METS et 8,43 ± 1,35 vs METS et 5,42 ± 1,39 et 6,75 ± 1,37 METS; MiCoach, 5,43 ± 0,95 et 8,33 ± 1,49 METSvs 5,27 ±0,89 et 7,59 ± 1,16 METS; et de l'action, 4,94 ± 1,60 et 7,47 ± 1,90 METS vs 1,75 ± 0,35 et 3,08 ± 0,66 METS. En outre, il y avait une tendance, où, pour le même jeu, une DE

supérieure moyenne a été observée avec la console Kinect (495,0 ± 119,6 kcal / h pour JustDance Kinect vs 414,9 ± 9 ± 70,7 kcal / h pour JustDance PS3Move ; p = 0,045 et 444,6 ± 88,7 kcal / h pour miCoach Kinect et 432,4 ± 80,2 kcal/h pour miCoach PS3Move; p = 0,200). Conclusion: Selon les normes ACMS, JustDance et miCoach atteignent un niveau d'intensité modérée à vigoureuse (3 METS à 6 METS). En atteignant ces exigences en activité physique, ces jeux vidéo actifs peuvent fournir des outils importants pour la promotion de l'activité physique chez les joueurs adultes inactifs.

6.3. Article

6.3.1. Title: Comparison of various active video games and consoles on the energy expenditure and cardiorespiratory responses in young male adult gamers.

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6.3.2. Abstract

Purpose: Different active video games combines pleasure and an easily accessible practice of physical activity, provided that they are sufficiently intense and motivating. However, it is unknown which video game consoles and video game types allow enough physical activity intensity to meet the standards of the American College of Sports Medicine (ACSM). **Methods:** A total of 10 inactive male gamers (aged 26±5 years), were recruited to measure the energy expenditure (EE) required by three types of games on different consoles. The following consoles were selected: PlaystationMove and Kinect, and three categories of games: dance (Just Dance 3,), training (MiCoach) and action (Star Wars for Kinect and No More Heroes for PSMove). **Results:**The average and peak METS (mean±SD) on both Kinect vs. PlayStationMove, respectively: JustDance, 6.87±1.26 METS and 8.43±1.35 METS vs. 1.39±5.42 METS and 6.75±1.37 METS; MiCoach, 5.43±0.95 METS and 8.33±1.49 METS vs. 5.27±0.89 METS and 7.59±1.16 METS; and action, 4.94±1.60 METS and 7.47±1.90 METS vs. 1.75±0.35 METS and 3.08±0.66 METS. In addition, there was a tendency, not always significant, where for the same game, a higher mean EE was observed with the Kinect (495.0±119.6 kcal/h for JustDance Kinect vs. 414.9±9±70.7 kcal/h for JustDance PS3Move; p=0.045 and 444.6±88.7 kcal/h for MiCoach Kinect and 432.4±80.2 kcal/h for MiCoach PS3Move; p=0.200). **Conclusion:** By ACSM standards, JustDance and MiCoach achieved a level of moderate to vigorous intensity (3 METS to ≥6 METS), and by reaching the physical activity requirements, they can provide important tools for physical activity promotion in inactive adult gamers .

Keywords: Active Video Game, exergames, physical activity requirements, inactive adults, gamers

Abbreviations:

ACSM: American College of Sports Medicine

ANOVA: Analysis of variance

BMI: Body Mass Index

bpm: beat per minute

cm: centimeter

CSEP: Canadian Society for Exercise Physiology

DDR: Dance Dance Revolution

EE: energy expenditure

hr: hour

HR: heart rate

JD: Just Dance

JDK: Just Dance with Kinect captor

JDPS: Just Dance with PlayStation3 Move captor

JDPSs: JDPS: Just Dance with PlayStation3 Move captor in sitting position

Kcal: Kilocalorie

kg: kilogramme

MC: MiCoach

MCK: MiCoach with Kinect captor

MCPS: MiCoach with PlayStation3 Move captor

min: minute

ml: millilitre

MET: Metabolic Equivalent of Task

MMORPG: Multiplayer Online Role-Playing Game

PAR-Q: Physical Activity Readiness Questionnaire

PS: PlayStation

SD: standard deviation

SWK: Star Wars with Kinect captor

NMHPS: No more Heroes with PlayStation3 Move captor

NMHPSs: No more Heroes with PlayStation3 Move captor in sitting position

VO2: Volume of oxygen uptake

VO_2max: maximal volume of oxygen uptake

6.3.3. Introduction

Video game usage is increasingly prevalent and emerges as a new lifestyle and culture that represents Gamers (Wirman 2007). Gamers were defined by Siegel (2009) by individuals playing on a regular basis and composed 25% of the population that play computer and video games. However, this definition changes depending on the author, mostly due to a new problem where video games can cause an excessive, addicting, problematic lifestyle in some gamers (Charlton and Danforth 2010; Gentile et al. 2011; Groves et al. 2015; Lafreinère et al. 2009; Sharer 2012).The definition of gamers is criticized and debated, and are mostly represented by the addiction and dependance pathology due to this new culture (Gentile et al. 2011; Sharer 2012). Smahel et al. (2008) found that the average playing time for Massively Multiplayer Online Role-Playing Game (MMORPG) players was 23 hours a week, where 9% reported playing more than 40 hours a week. In this 9% of gamers only 40% of them self-identified as being addicted. A number of reasons can explain the displacement of time that these gamers undergo including the sense of flow (pleasure immersion in everyday activity) and losing track of time (Ballard et al. 2009). Thus, the present study will use Shepard's gamer definition and the 7Es (Thirunarayanan and Vilchez 2012), respectively as: "one who has taken a form of gaming [...] and made it a part of their life-style" and where the seven categories that have emerged regarding the identity of a gamer: Engagement, Enjoyment, Equipment, Existential, Experience, Expertise and Extend. With such importance of gaming in their life, it may be complicated to find time for physical activity, like in many modern adult lifestyles (Stutts 2002).

Video game playing has also been associated with sedentary time. In fact, sedentary (sitting) time is increasing in society and is becoming ubiquitous in industrialized countries (Tremblay et al. 2011). Several studies have reported that time spent in sitting position watching a screen is correlated with a higher risk of diabetes mellitus, obesity, cardiovascular disease and death regardless of the level of physical activity participation (Balducci and Zanuso 2009; Stamatakis, Hamer, and Dunstan 2011; Wilmot et al. 2012). Furthermore, screen time seems to replace physical activity according to Ballard et al. (. 2009), and physical inactivity is known to be associated with global health problems such as cancer, hypercholesterolemia, and cardiovascular disease (Ballard et al. 2009).

To counter the epidemic of inactivity, numerous physical activity guidelines have been established and made public (Garber et al. 2011; Tremblay et al. 2011). However, in Canada, only half of the population actually follow these guidelines (Colley et al. 2011) and this figure is even smaller in the United States (Haskell et al. 2007). Recent recommendations (2011), suggest that the overall total activity time can be completed in bouts of 10 minutes or more to accumulate 150 min of moderate to vigorous intensity aerobic physical activity per week, equivalent to a minimum of 1000 kcal/week(Garber et al. 2011; Tremblay et al. 2011). The Institute of Medicine, the International Association for the Study of Obesity, and the Dietary Guidelines Committee all support the recommendation of at least 150 minutes of moderate to vigorous physical activity, but emphasize the need for a greater physical activity volume to elicit increasing energy expenditure(Siegel et al. 2009). The problem is that time can be seen as a barrier to physical activity and some activities like cycling or walking, proposed in the guidelines, are considered as unattractive or unenjoyable for a young adult, such as a college student (Siegel et al. 2009).

Previous studies have proposed that increased physical activity levels and energy expenditures can be achieved with active video games such as Nintendo Wii, Dance

Dance Revolution, and EyeToy (Bidiss and Irwin 2010; Donovan and Hussey 2012; Duncan and Staples 2010; Mark et al. 2008; Miyachi et al. 2010; Siegel et al. 2009; Smallwood et al. 2012; Stroud, Amonette, and Dupler 2010). However, the ACSM and Canadian Society for Exercise Physiology (CSEP) (Garber et al. 2011; Tremblay et al. 2011) currently do not recommend using this technology to increase physical activity time due to the low intensity of exercise associated with these game systems (Bidiss and Irwin 2010). It should be noted though that the majority of these studies didn't take into consideration the type of game, the difficulty level, and the specific console. Despite this, commercially available active video game systems have evolved in different directions. Two main game controllers are generally available: i) the movement tracking system, where a camera detects the player's body and integrates it with the game (for example; Eye Toy and Kinect), and ii) a controller system where the player interacts with the game via a controller in their hand (such as the Nintendo Wii and the PlayStation3 Move) or via a foot operated pad such as Dance Dance Revolution(Sinclair, Hingston, and Masek 2007). The differences in these control devices, the gameplay, and the level of difficulty of the game may affect energy expenditure during active video gaming depending on the study design (Bidiss and Irwin 2010; Miyachi et al. 2010; Sinclair, Hingston, and Masek 2007). Gameplay is defined in many ways depending on the authors. However, this concept remains to be defined precisely due to not only its importance on the game quality in the mind of many players (Djaouti et al. 2008), but also on the physiological responses contributing to contradictory conclusions in previous studies (Biddiss and Irwin 2010; Miyachi et al. 2010; Sinclair, Hingston, and Masek 2007).

For the present study we used a gameplay definition combined from the work of Crawford and Rutter (2007), and Ermi and Mäyrä 2005; where the gameplay is described as a derived combination of pace and cognitive effort required by the game, and where particular skills are developed, both motor and cognitive, in order to engage the player by the structure of the game. Furthermore, Djaouti et al (2008) present their gameplay concept as two main types, composed of "game bricks" related to the goals reached by the feedback performance returned by game elements to the player and the "play bricks" that represent a means (or constraints) to reach this goal where the acting or skills are consequently of the game feedback. Extrapolating these definitions and concepts to active video games; the gameplay needs to take into consideration the fitness requirements and motor control to achieve the game. That includes the type of exercises intended, the pace (imposed rhythm) and the level of recognition by the console, if it allows general or perfect technique movement and feedback to engage the player. However, comparing gameplay and the console type is relatively unexplored, particularly among adults and it is essential to be able to make proper recommendations for using these devices in physical activity promotion.

Thus, this study was designed to compare physiological responses and the energy expenditure of different console designs (movement tracking vs. controller), and different gameplays (dance, training, and action) to observe which can reach the ACSM physical activity guidelines (Garber et al. 2011). Specifically, the objectives were (1) to compare the same games with different console designs: movement tracking vs. controller; (2) to compare different gameplays: dance, training, and action game; and (3) to compare the same games playing with a controller console design in a sitting vs. standing position. Finally, the last objective was to determine which active video game on the different consoles can reach the minimum recommendations for daily physical activity according to the ACSM guidelines, a minimum energy expenditure (EE) of 3 METS (moderate exercise). It was hypothesized that a significant difference between gameplay and consoles would be observed, where the training game would generate a considerably greater energy expenditure than the other game types and possibly higher with the movement tracking system than the controller system. This hypothesis emerged as a result of the possible recruitment of bigger muscle mass by the structure/gameplay of the game, where the training gameplay is similar to traditional high-intensity cardiovascular and muscular program training. Furthermore, the motion tracking system tracks the entire body where the controller detects only the movement of the hand and allows the player to minimize the precision of the exercise to be detected to reach the game goal.

6.3.4. Methods

Participants

A total of 10 male participants, mean age 26 (±5) years, who played video games regularly (22.5 ±13.4 hr/ week) and engaged in less than 180 minutes of free structured activity or less than 120 min of structured physical activity per week were recruited. The criteria for recruiting gamers was set at a minimal gaming time of 5 hrs/ week according to Mentzoni et al. 2011, where they observed that the weekly average amount of gaming time for males aged between 20-35 years old was 5.5 ± 2.7 hrs/week. This criteria was selected because of the lack of a precise amount of time describing a gamer. Most of the studies focused on the psychopathology and required complex analysis of video game obsession and the way it interferes with social, occupational and academic life (Lafreinère et al. 2009; Sharer 2012). However, it was important to have experienced video game players in order for them to understand a minimum about the games structures/gameplay, given that they didn't have practice before the gaming session. Those with a cardiorespiratory disease, musculoskeletal injury or other physical activity restrictions were excluded from the study. All participants were non-smokers. Ethics approval for this study was obtained from the Institution Revision Board for Research on Humans Ethics Committee of the University of Quebec in Montreal's Faculty of Science. Written informed consent was obtained from all participants. The PAR-Q (Physical Activity Readiness Questionnaire), heart rate, and blood pressure at rest were also required before the tests according to the Canadian Society for Exercise Physiology (CSEP/ SCPE 2003) guidelines for safe physical activity participation with inactive individuals.

Interventions

Video game and console choice

The consoles chosen for active video games were the Kinect (XBOX 360, Microsoft, USA) for the movement tracking system and the PlayStation Move (PlayStation3, Sony, Japan) (PS) for the controller system. The PS was selected rather than the Wii (Nintendo,) for the controller system given that games were available on both consoles (Kinect and PS), something not possible with the Wii. The three game categories were: dance (JustDance 3), personal trainer, or also called training game (MiCoach,) and a hack-and-slash, a particular form of action game characterized by an emphasis on the combat (No More Heroes: Heroes' Paradise for PS and Star Wars for Kinect). Unfortunately, the hack-and-slash game and other adventure games were not available on both consoles for this study.

The PS was performed under two conditions: sitting and standing up position. The reason was to play different gameplays in a sitting vs. standing position. However, it was not possible to perform with a movement tracking system in sitting position. Furthermore, the training game, MiCoach, did not allow for a sitting position performance due to body motion tracking with the camera combined with the controller. This was not the case for the other games where only the controller movement was tracked. It was for this reason that only the dance and the action games were performed with the PS controller system for the comparison between a sitting and standing position.

The level of difficulty chosen in the game was linked to the EE during an active video game play time which explains contradictory results in previous studies (Sell, Lillie, and Taylor 2010). It is why the choice of the level, gaming time (which needed to be around the same; 12-15min) and progression in the games were standardized. This is described in the following paragraph.

*Dance Game (JD).*The choice of the dances in Just Dance (JD) was according to the highest sweat points; these points are linked with the imposed tempo of the dance. A higher sweat point identifies higher imposed pace and difficulty at the same time. In the present study, Party Rock Anthem, No Limit, Land of 1000 Dances were chosen, for a total of 15 minutes of gaming with a total loading time between the dances of around 3 minutes. *Training Game (MC)*: The training selected in MiCoach (MC) was the general fitness (both muscular and cardiovascular training) at the beginner mode, given that the participants had a sedentary lifestyle and it represented a general exercise training of around 13 minutes of active gaming. *Action game (SWK and NMHPS)*: The Star Wars Kinect game (SWK) was in the story mode (Jedi Destiny) at Chapter 2: Providence given that it was a chapter where the hack-and-slash, combat movements, requirement was in continuous action for minimally 12 minutes, and around 15 minutes with the loading time and a cut scene between the 2 chapters. The No More Heroes game was chosen for PS (NMHPS) because the gameplay is based on a hack-and-slash gameplay, which is rarely developed for this console at the time of the present study. The level of the game was set at Sugar (easy) to allow the participants to play for minimally 12 consecutive minutes.

Physical Assessments

Anthropometry was measured at the beginning of the study. This measurement consisted of height, weight and body fat percentage by bioimpedance (Tanita, Arlington Heights, Illinois); the body mass index (BMI) was calculated.

A submaximal one step test was performed. The test had three pace levels, pre-recorded at 18, 24 and 30 beats/min respectively, of three minutes long each. The participants had to synchronize their steps with the imposed tempo, where the step climbing movement was distributed into four beats. The heart rate was measured and noted at the end of each stage. The ACSM VO_2 step test equation (ACSM 2010) was used to extrapolate the VO_2max of the participants. The heart rate was measured by a heart rate monitor (RS800, Polar, Fi). The exhausted perception was also taken at the end by the OMNI scale(Utter et al. 2004). A cooldown of five minutes after the submaximal aerobic test was recorded.

Video Game Activities

The total of each active gaming session was between 12-15 minutes of active gaming, without the loading time of the game. The order of the games was semi-random, where the games were set in different orders, and were randomly associated with a participant. EE was measured using a portable breath by breath metabolic analyzer (k4b2, Cosmed, Italy) and the heart rate with a heart rate monitor (RS800, Polar, FI). After each session, the participants had a minimum of 30 minutes of rest. The exhausted perception (OMNI) was taken at the end of each session for the cardiorespiratory perception effort and muscular perception effort.

Rest time

During the rest time, the participants were permitted to play inactive games. A heart rate monitor measured the heart rate during this period and an expenditure energy armband (Armband, Bodymedia Senswear, USA) measured the activity throughout the study to ensure that participants remained at rest during the rest period.

Data Analysis

Data from the metabolic analyzer were averaged over ten second increments. The results were presented in mean ± standard deviation form. Paired t-test and ANOVA repeat measure, and a Bonferroni-corrected pairwise comparison were conducted to assess between the energy expenditure (EE and METs) and cardiovascular responses (VO_2, HR) of the different games and consoles ($p<0.05$). Data were analyzed using SPSS 20 (IBM).

6.3.5. Results

Descriptive data of the participants are presented in Table 6.1. The overall mean %Fat and BMI reveals that the participants were overweight and the VO_2max extrapolated is typical of an inactive lifestyle of the participants. The energy expenditure and cardiovascular responses to the various games in the different consoles are shown in Table 6.2.

Consoles: Kinect vs. PS

It is possible to observe a wide dispersion of cardiorespiratory and EE parameters that are significantly different between consoles for the dance game than the training game, where the tracking system showed a higher induced intensity. The mean METS average was significantly higher with the movement tracking system (Kinect) ($p=0.003$) for the dance game (JD), but not for the training game (MC) ($p=0.131$).The total energy expenditure was significantly higher with the Kinect system during JD ($p=0.002$), but not for MC ($p=0.522$) and mean heart rate was significantly higher with the Kinect system for the JD ($p=0.05$), but not with MC ($p=0.677$). However, some peak parameters showed a significant difference between consoles for the dance and training games. The peak METS for JD and MC games were significantly higher with the movement tracking system for both games: dance game with the Kinect system (JDK) vs. dance game on the controller system (JDPS); $p=0.17$ and MCK vs. MCPS, $p=0.033$). The peak $\%VO_2$ for the JD and MC games were significantly higher with the movement tracking system for both games: JDK vs. JDPS; $p=0.023$ and MCK vs. MCPS $p=0.038$, and the peak expenditure energy (kcal/h) was significantly higher with the Kinect system: JDK vs. JDPS; $p=0.013$ and MCK vs. MCPS $p=0.033$. Nonetheless, the effort perception (OMNI scale) for resistance type exercise (muscular group resistance exercise, e.g., push-ups) and cardiorespiratory perception were not significantly different between consoles for JD. However, MC had a significantly higher cardiorespiratory effort perception with the Kinect ($p=0.021$), but no significant difference was observed for the muscular effort perception. On another note, it is important to notice that the action games were not the same game and that can explain the significant difference in the parameters ($p<0.001$ to $p=0.037$).

Gameplays: Dance vs. Training vs. Action

There was a significant difference between the different gameplay. The main difference is the action games, where No More Heroes on PS (NMHPS) showed all parameters were significantly lower than Star Wars on kinect (SWK); p varied between $p<0.001$ and $p=0.037$. Furthermore, the dancing gameplay induced the same or even significantly higher intensity than the training game, where the VO_2mean ($p=0.024$) and the %time of moderate and vigorous activity ($p=0.013$) was significantly higher for JDK. However, the %time of moderate activity ($p=0.013$), the effort perception by the OMNI scale for cardiorespiratory and muscular effort perception ($p=0.005$ and <0.001 respectively) was significantly higher for the MCK. Notice that it was observed on the movement tracking system only.

Sitting VS. standing position

The EE for the dance games in a sitting position (JDPSs) was significantly lower than the original controller dance game in standing position ($p<0.001$). However, it is possible to observe the mean METS for the JD at 3 ± 1 METS, corresponding to a moderate intensity(Garber et al. 2011). Furthermore, this intensity can be maintained during 45±40% of the gaming time. On the other hand, the controller action game in a sitting position (NMHPSs) seems to induce no or a very low physical activity level (METS mean at 1.5 ±0.2). Also, no significant difference was observed between the sitting position and the standing position for this game, maybe due to the low intensity of the original game (METS mean at 1.7 ± 0.3) (Table: 6.3).

Intensity level, EE of the game and enjoyment

METS reached while playing active video games are presented graphically in Fig 6.1. The average METS for the tracking movement system (Kinect) and the controller system (PS) for JD (7±1 and 5±1, respectively), MC (5±1 for both console), and SWK games (5±2) reached the moderate intensity level defined by the ACSM (3 to 5.9 METS)(Garber et al. 2011) (Fig. 7.3-1B). Also, the games can reach vigorous intensity (≥6 METS) for a significant amount of time; 66±18% for JDK, 37±23% for MCK, 38±27% for JDPS, and 31±23% for MCPS (fig.7.3-1A). However, NMHPS cannot reach the minimum required by the ACSM, a moderate intensity level, for a significant amount of time (4±6% of the session). The percentage of time in the moderate and vigorous intensity can reach more than 85% for the majority of the active video game. Furthermore, the oxygen consumption reached between 40 and 60% of the extrapolated VO_2max (Fig.6.2C). The EE is presented in Table 6.2 and Fig. 6.1C. Finally, the participants answer that their more enjoyable game was at 40% SWK, 40% JD, 10% NMH, and 10% MC and the game with the higher perception of training was at 100% MC.

6.3.6. Discussion

The purpose of this study was to compare EE with 1) different consoles, 2) different active video gameplay and 3) standing vs. sitting position. Furthermore, we hoped to determine whether the gamers were able to reach the minimum daily physical activity required by ACSM guidelines (Garber et al. 2011). The main finding from this study was that the EE can achieve moderate to vigorous intensity requirements as defined by ACSM guidelines, that reached 3 to 5.9 (moderate intensity) on to 6 METS and more (vigorous intensity), for the JD, SWK, and MC gameplay (Garber et al. 2011). This result disputes previous findings (Bidiss and Irwin 2010; Donovan et al. 2012;

O'Donovan et al. 2012) where using active video games, gamers were unable to meet the minimum requirements for daily physical activity. Moreover, a higher intensity (METS) was observed with the movement tracking system (Kinect) than the controller system (PS) during playing the same game. This result corroborates the study of O'Donovan et al. (2012), but contradicts the previous finding where no significant difference was found between consoles using similar, but not the same, games at light intensity with an older population(Taylor et al. 2012).

In addition, we report that a significant difference was detected between gameplay type, where the training game and the dance game reached a higher intensity than the action games. These action games, however, are suggestive of depending highly on the gameplay/structure of the game and need to be tested before selecting them for a physical activity promotion purpose. It is important to notice that the action gameplay was different between SWK vs. NMHPS. The movement requirement for NMHPS especially focused on button controls rather than arm movements to induce game damage and reach the game goal. However, SWK game focused on the arms movement and executed jumps by the participant to accomplish the mission, recruiting more muscle mass and inducing a higher EE. It was unexpected that the dance gameplay was able to generate the same or even significantly higher intensity than the training game, knowing that the structure of the training game is the same as a training program proposed in a gym. However, the dance game has a video game dance structure (like DDR or Eye Toy Groove) that allows to generate physical efforts requiring about 3 METS and less according to previous studies (Biddiss and Irwin 2010; Smallwood et al. 2012). It is meaningful that the effort perception was significantly higher for the training game even if the % of time at vigorous effort was significantly superior during JD. Finally, the sitting position in an active video game can reach moderate intensity (3.0 to 5.9 METS) for the dance gameplay and this suggests that such a game can be a valuable tool for people that may be older with limited ambulatory qualities, or with a balance disability, or spinal cord injuries.

ACSM Norms

The ACSM physical activity guidelines recommend that most adults should engage in moderate or vigorous intensity cardiorespiratory exercise or a combination of those to achieve a total EE of ≥500-1000 MET*min*week^{-1} (Garber et al. 2011). Moderate exercise is associated with an intensity of approximately 3.0-5.9 METS and vigorous exercise is equivalent to 6 or more METS. JustDance (~ 96% Kinect and 89% PS), MiCoach (~ 93% Kinect and 91% PS) and Star Wars (~87%) had more than 85% of the gaming time over 3 METS. The time spent at less than 3 METS was probably due to rest for the game loading or the cut scene that cuts the exercise and allows an interval training approach when played for at least 30 min. Playing this game can be equal to 4 effort sets of around 6 minutes at around 66% VO_2max with rest interval sets of around 2 minutes long, depending on the game loading or cut scenes. The time at vigorous intensity, ≥6 METS was substantial: 66±18% for JDK, 37±23% for MCK, 38±27% for JDPS and 31±23% for MCPS), mostly, because most of previous publications seem to indicate that it is impossible to reach this intensity with an active video game (Biddiss and Irwin 2010) even more for an important period of time.

The ACSM guidelines recommend a target starting at 500 kcal/week to achieve significant risk reductions of cardiovascular disease and premature mortality. This recommendation is equivalent to playing JDK for 63 min/week or 69 min/week with JDPS or MCK for ~ 68 min/week and MCPS for 69 min/week or SWK for ~ 81 min/week. All these equivalents are less than the 150 min/week of moderate intensity or 75 min/week of vigorous intensity of cardiorespiratory exercise recommended by the ACSM. Considering the fact that time is the biggest constraint mentioned by inactive adults(Stutts 2002), using active video game can be a valuable tool as physical activity promotion.

Physiological response and recommendations

Significant benefits have been associated with lower guidelines than the ACSM guidelines (Garber et al. 2011;Tremblay et al. 2011). The minimum intensity to improve cardiorespiratory fitness and reduce cardiometabolic risks remains unclear and a topic of great debate (Garber et al. 2011; Siegel et al. 2009; Smallwood et al. 2012). It has been suggested that exercise at >40% VO_2max can improve the cardiovascular fitness (Garber et al. 2011). Also, moderate activity is classified at 64-76% HRmax, 46-63% VO_2max and an effort perception at fairly light to somewhat hard (2-5 on the Omni scale), which is the minimum intensity to have an active lifestyle (Garber et al. 2011).This study showed that Just Dance, MiCoach, and Star Wars can allow the player to reach levels of EE comparable to these requirements and, therefore, may be viable tools to improve physical activity and their health benefits, as has been proposed in previous studies (Bidiss and Irwin 2010; O'Donovan et al. 2012; Siegel et al. 2009).

Due to the population of gamers, the controller system can require less EE than the movement tracking system, possibly because they can minimize the effort needed to recognize the movement (cheat) and stimulate less important muscular mass, like legs, to accomplish the task. It is probably for this reason that MiCoach had no significant difference, for the averaged parameters, between the consoles; for this game, the tracking was effectuated mostly with the eyes (a type of movement tracking) and it minimally uses the controller to track the movement. However, the controller can allow a participant with a spinal cord injury or other lower limb disability and/or balance deficits to play an active video game (Bidiss and Irwin 2010; Taylor et al. 2012; Taylor et al. 2011). Unfortunately this is not possible with a movement tracking system. Furthermore, the energy expenditure observed during the present study in a sitting position shows that it is possible to increase the amount of physical activity at home and reach minimum intensity level (3 METS) with this population (spinal cord injuries, post-stroke patients...). Knowing that it can be complicated for them to move outside and have access to adapted physical activities (Gaffurini and Bissolotti 2013; Lohse et al. 2013), the present study results can help to create future physical activity projects and/or new games developments. Previous studies have used an active video game to elevate enjoyment of physical therapies and improve the access by performing the program at home (Bidiss and Irwin 2010; Sell, Lillie, and Taylor 2010). The present study shows that the energy expenditure in a sitting position can reach moderate intensity. However, the game needs to be chosen carefully, for example, 45% at 3 to 5.9 METS with JDs but none with NMHPSs.

Limitations

One of the limitations of this study was that the portable metabolic analyzer used may restrain movement in participants and therefore possibly lead to an underestimation of the EE (Miyachi et al. 2010). Another factor to consider is the motivation of the participant; active video gaming, like any other physical activity, depends on the participant's motivation to engage in the activity. Furthermore, the participant was in a laboratory accompanied by a research team, which did not replicate the home environment. However, we noticed that participants did appear to become immersed in the game and did not seem uncomfortable in this situation.

6.3.7. Conclusion

This study showed that using a dance game such as Just Dance and a training game like MiCoach can achieve the EE requirements (ACSM guidelines (Garber et al. 2011)) using both consoles (movement tracking system and controller system). The movement tracking system (Kinect), however, appeared to increase the intensity of the activity more than using a controller system (PS). Moreover, the gameplay of action games significantly differed depending on the gameplay (exercises required) and can, for some gameplays, reach the physical activity guidelines, as for SWK. On the other hand, it was not the case of NMH. These active video game technologies evolve rapidly and will require critical thinking as well as further research on them and their future gameplays and tracking system.

6.3.8. Acknowledgements

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SUMMARY BOX

- A motion capture movement device induces a higher EE.
- The dance game and training game reached ACSM requirements for an active life style.
- The dance game when playing in sitting position can induce an intensity acceptable to participants with restrictions.

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6.3.10. Tables:

Table 6. 1: Characteristics of the participants

Characteristics	**Mean±SD**
Age (years)	26 ± 5
Height (cm)	178.5 ± 6.0
Weight (kg)	82,4 ± 23,0
BMI (kg/m^2)	25.9 ± 8
% Fat (%)	18.4 ±3,9[n]
VO_2 max $_{extrapolated}$ (ml/kg/min)	36.5 ± 4.9
Resting heart rate (bpm)	78 ± 10

[n] n=8 participants bioimpedance scale problem

Table 6. 2:EE and cardiovascular responses to gaming conditions

Consoles	Kinect	PS
Just Dance	JDK[nn]	JDPS[n]
Min heart rate (bpm)	111 ± 24	96 ± 19*[C]
Peak heart rate (bpm)	171 ± 25	158 ± 20
Mean heart rate (bpm)	145 ± 22	130 ± 18
Peak VO_2 (ml/kg/min)	31 ± 4	26 ± 5*[C]
Peak VO_2 (ml/min)	2330 ± 299	2018 ± 228*[C]
Mean VO_2 (ml/min)	1853 ± 394	1887 ± 1333
Peak % VO_{2max} (%)	74 ± 13	66 ± 16*[C]
Peak EE (Kcal/h)	708.8 ± 115.5	597.6 ± 71.3*[C]
Mean EE (kcal/h)	495.0 ± 119.6	414.9 ± 70.7*[C]
Total EE / total gaming time (Kcal/min)	7.89 ± 1,41	6.55 ± 1.21*[C]
% time of 3 to 5.9 METS (%)	30 ± 16	51 ±20*[C]

% time $\geq$ 6 METS (%)	66 ± 18	38 ± 27*^{C}
Mean METS	7 ± 1	5 ± 1*^{C}
Peak METS	9 ± 1	7 ± 2*^{C}
Min METS	2.4 ± 0.6	2.2 ± 0.6
OMNI cardiovascular	6 ± 2	5 ± 2
OMNI muscular	3 ± 2	3 ± 2
MiCoach	MCK	MCPS^{n}
Min heart rate (bpm)	110 ± 14	105 ± 22
Peak heart rate (bpm)	170 ± 12	166 ± 21
Mean heart rate (bpm)	139 ± 16	139 ± 21
Peak VO_2 (ml/kg/min)	29 ± 5	26 ± 4*^{C}
Peak VO_2 (ml/min)	2250 ± 263	2076 ± 255*^{C}
Mean VO_2 (ml/min)	1475 ± 298*^{T}	1442 ± 264
Peak % VO_{2max} (%)	75 ± 17	67 ± 16*^{C}

Peak EE (Kcal/h)	683.4 ± 77.4	627.2 ± 82.8*^{C}
Mean EE (kcal/h)	444.6 ± 88.7	432.4 ± 80.2
Total EE / Total gaming time (Kcal/min)	7.34 ± 1,43	7.23 ± 1.43
% time of 3 to 5.9 METS	56 ± 18*^{T}	60 ± 19
% time $\geq$ 6 METS	37 ± 23*^{T}	31 ± 23
Mean METS	5 ± 1*^{T}	5 ± 1
Peak METS	8 ± 1	7 ± 1*^{C}
Min METS	2.7 ± 0.5	2.6 ± 0.5
OMNI cardiovascular	7 ± 2*^{T}	8 ± 2*$^{T \text{ and } C}$
OMNI muscular	6 ± 2*^{T}	6 ± 1*^{T}
Action Game	SWK	NMHPS
Min heart rate (bpm)	96 ± 26*^{T}	76 ± 17*$^{T \text{ and } C}$
Peak heart rate (bpm)	151 ± 26*^{T}	121 ± 18*$^{T \text{ and } C}$
Mean heart rate (bpm)	125 ± 28*^{T}	97 ± 16*$^{T \text{ and } C}$

Peak VO_2 (ml/kg/min)	26 ± 6	11 ± 2* $^{\text{T and C}}$
Peak VO_2 (ml/min)	1988 ± 515	843 ± 199*$^{\text{T and C}}$
Mean VO_2 (ml/min)	1319 ± 405*$^{\text{T}}$	481 ± 111* $^{\text{T and C}}$
Peak % VO_{2max}	66 ± 22	27 ± 8* $^{\text{T and C}}$
Peak EE (Kcal/h)	583.2 ± 160.1	243.9 ± 58.5* $^{\text{T and C}}$
Mean EE (kcal/h)	407.3 ± 129	140.2 ± 32.2 $^{\text{T and C}}$
Total EE / Total gaming time (Kcal/min)	6.24 ± 2.15	2.54 ± 1.09 * $^{\text{T and C}}$
% time of 3 to 5.9 METS	74 ± 14*$^{\text{T}}$	4 ± 6 * $^{\text{T and C}}$
% time ≥ 6 METS	13 ± 14*$^{\text{T}}$	0 ± 0* $^{\text{T and C}}$
Mean METS	5 ± 2* $^{\text{T}}$	1.7 ± 0.3 * $^{\text{T and C}}$
Peak METS	7 ± 2	3 ± 1* $^{\text{T and C}}$
Min METS	2.6 ± 0.6	1.1 ± 0.2 * $^{\text{T and C}}$
OMNI cardiovascular	4 ± 2 *$^{\text{T}}$	1 ± 1 * $^{\text{T and C}}$
OMNI muscular	3 ± 3	1 ± 1 * $^{\text{T and C}}$

[a]: n= 9, device measures failure

nn n=8, device measures failure
*C Significant different $p < 0.05$ between the consoles (same type of game)
*T Significant different $p < 0.05$ with the Dance Game (same console)

Table 6. 3:Cardiovascular response to standing VS. siting position

	Standing	**Sit position**
Just Dance	JDPS	JDPSs
Min heart rate (bpm)	96 ± 19	79 ± 16*P
Peak heart rate (bpm)	158 ± 20	127 ± 16*P
Mean heart rate (bpm)	130 ± 18	104 ± 15*P
Peak VO_2 (ml/kg/min)	26 ± 5	19 ± 7*P
Peak VO_2 (ml/min)	2018 ± 228	1445 ± 468*P
Mean VO_2 (ml/min)	1887 ± 1333	862 ± 265
Peak % VO_{2max}	66 ± 16	48 ± 19*P
Peak EE (Kcal/h)	597.6 ± 71.3	426.8 ± 136.5*P
Mean EE (kcal/h)	414.9 ± 70.7	247.8 ± 82.4*P
Total EE/Total gaming time	6.55 ± 1.21	4.07 ± 1.16*P

(Kcal/min)		
% time of 3 to 5.9 METS	51 ±20	45 ± 40
% time $\geq$ 6 METS	38 ± 27	2 ± 5*^{P}
Mean METS	5 ± 1	3 ± 1*^{P}
Peak METS	7 ± 2	5 ± 2*^{P}
Min METS	2.2 ± 0.6	1.6 ± 0.6
OMNI cardiovascular	5 ± 2	3 ± 1*^{P}
OMNI muscular	3 ± 2	3 ± 2

No More Heroes	NMHPS	NMHPSs
Min heart rate	76 ± 17	69 ± 13
Peak heart rate	121 ± 18	109 ± 16*^{T}
Mean heart rate	97 ± 16	88 ± 15*^{T}
Peak VO_2 (ml/kg/min)	11 ± 2	9 ± 2*$^{T \text{ and } P}$
Peak VO_2 (ml/min)	843 ± 199	698 ± 138*$^{T \text{ and } P}$
Mean VO_2 (ml/min)	481 ± 111	412 ± 53*^{T}

Peak % VO_{2max}	27 ± 8	23 ± 6* $^{T \text{ and } P}$
Peak EE (Kcal/h)	243.9 ± 58.5	243.9 ± 58.5* $^{T \text{ and } P}$
Mean EE (kcal/h)	140.2 ± 32.2	121.0 ± 15.3*^{T}
Total EE /Total gaming time(Kcal/min)	2.54 ± 1.09	2.12 ± 0.67* ^{T}
% time of 3 to 5.9 METS	4 ± 6	0 ± 1*^{T}
% time ≥ 6 METS	0 ± 0	0 ± 0
Mean METS	1.7 ± 0.3	1.5 ± 0.2* ^{T}
Peak METS	3 ± 1	3 ± 1* $^{T \text{ and } P}$
Min METS	1.1 ± 0.2	0.9 ± 0.1* $^{T \text{ and } P}$
OMNI cardiovascular	1 ± 1	0 ± 1*^{T}
OMNI muscular	1 ± 1	0 ± 1* $^{T \text{ and } P}$

*^{P} Significant different $p < 0.05$ between the positions (sitting and standing)
*^{T}Significant different $p < 0.05$ between the games (JDPSs and NMHPSs)

6.3.11. Figures

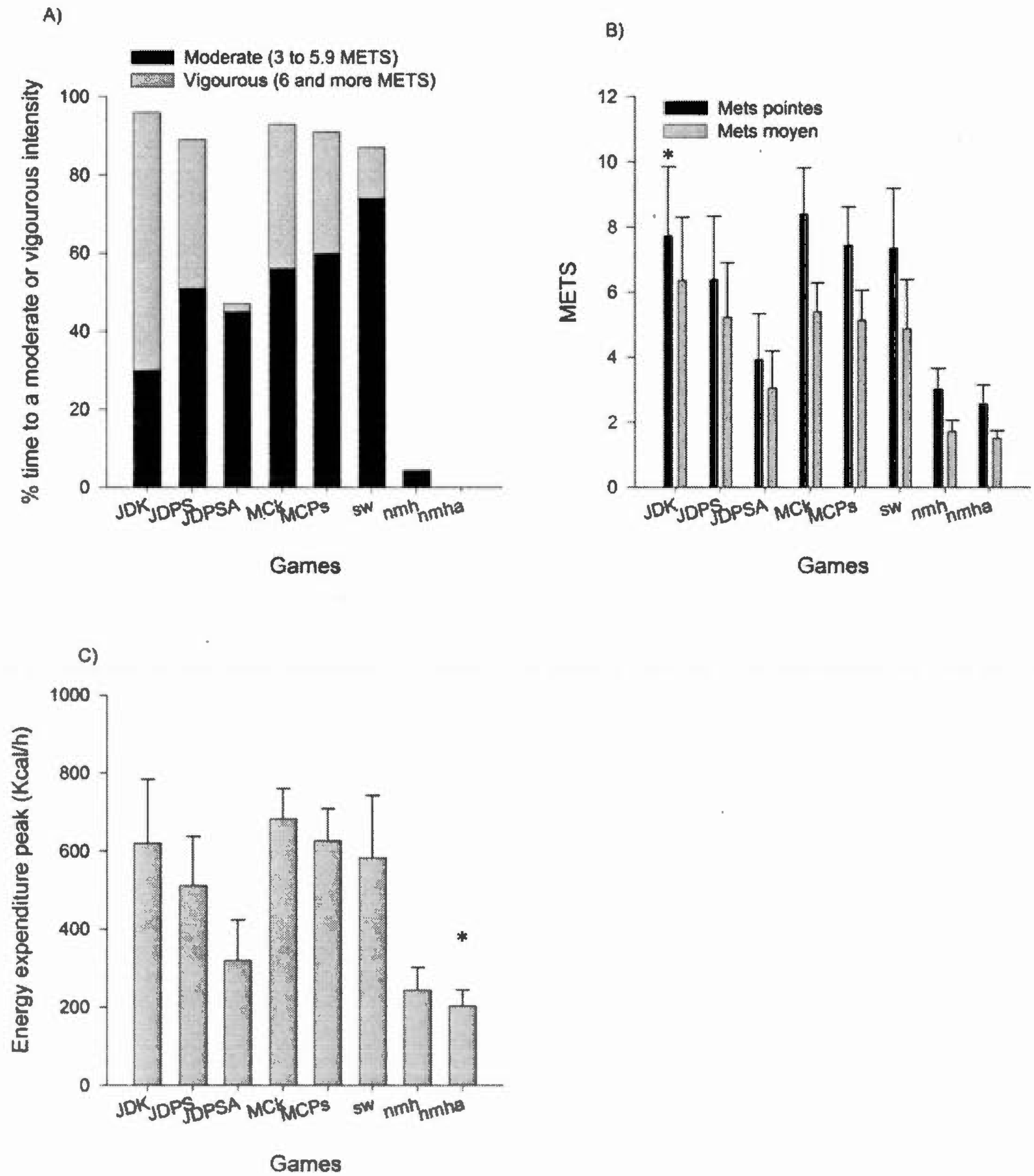

Figure 6. 1: Energy expenditure for different games: Just Dance with Kinect (JDK), Just Dance with PlayStation (JDPS), Just Dance with PlayStation in siting position

(JDPSs), MiCoach with Kinect (MCK), MiCoach with PlayStation (MCPS), action game with Kinect(SWK), action game with PlayStation (NMHPS) and action game with PlayStation in siting position (NMHPSs). A) Percentage of game time where the intensity was moderate and vigorous according to ACSM guidelines with video games; B) METS averaged and Peak METS during video games C) Peak EE during video games.

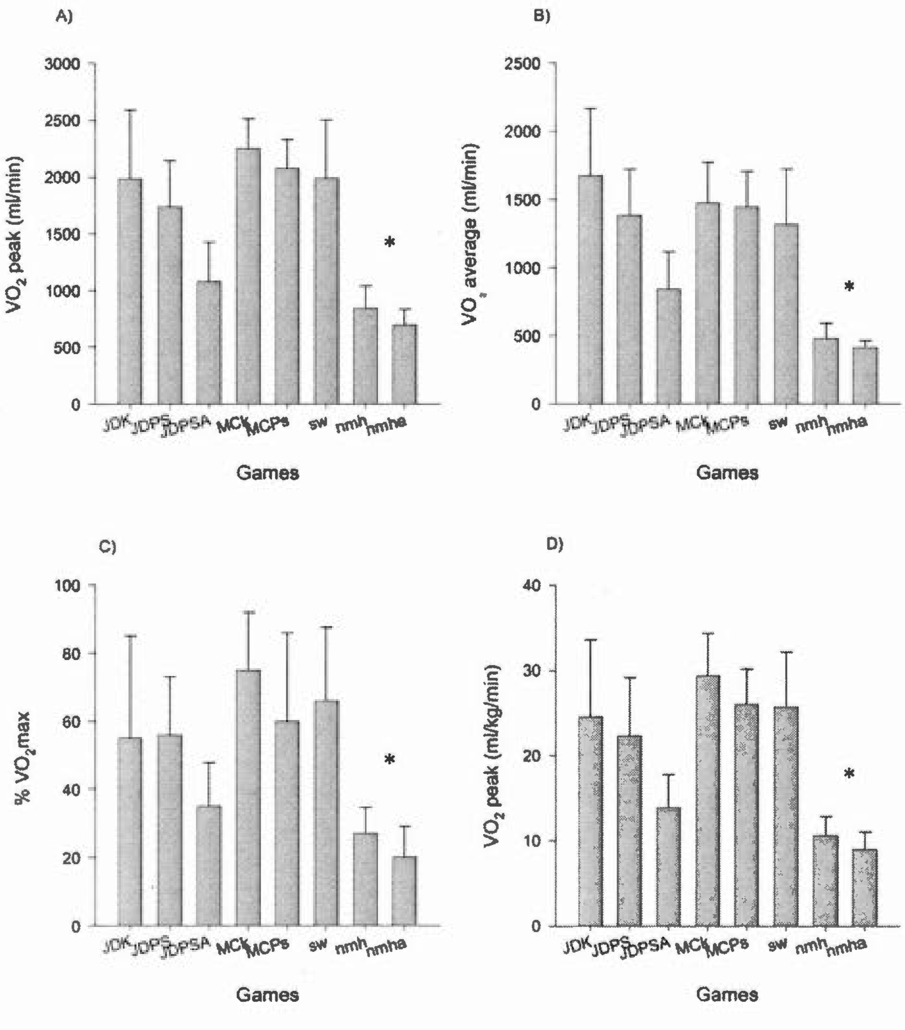

Figure 6. 2:Oxygen Uptake (VO_2) for different games: Just Dance with Kinect (JDK), Just Dance with PlayStation (JDPS), Just Dance with PlayStation in siting position (JDPSs), MiCoach with Kinect (MCK), MiCoach with PlayStation (MCPS), action game with Kinec(SWK), action game with PlayStation (NMHPS) and action game with PlayStation in siting position (NMHPSs). A) VO_2 peak during games; B) VO_2 averaged during games C) $\%VO_{2max}$ during games; D) Peak VO_2 in relative during games

CHAPITRE VII: MÉCANIQUE DE JEU VIDÉO ACTIF INNOVATEUR

7.1. Mise en contexte

Le chapitre précédent proposait d'observer 3 grands types de jeu vidéo classique qui se retrouve généralement sur le marché. Le présent chapitre présente un jeu vidéo actif innovateur par sa mécanique de jeu défiant ce qui était proposé précédemment par les autres jeux vidéo actifs. La mécanique de jeu demande à ce que le joueur exécute un maximum de répétitions d'un mouvement simple au lieu de suivre une cadence imposée par un entraîneur ou un autre aspect du jeu. Ce maximum demandé à travers des jeux de courte durée implique une intensité d'exercice hautement élevé de courte durée espacé par un repos, à la présentation des performances et de petites animations pour engager le joueur. Cette structure correspond à un mode d'entraînement qui a fait son essor dernièrement, l'entraînement par intervalle de haute intensité. Cette méthode se dit plus efficace qu'un entraînement traditionnel tout en étant sécuritaire (Gibala et al. 2006; Tabata et al. 1997).

7.2. Résumé

Objectif: L'objectif de l'étude était de déterminer si le nouveau jeu vidéo actif, Shape Up (Ubisoft Montréal) , pouvait répondre aux recommandations minimales d'activité physique quotidienne pour un mode de vie actif et si l'intensité des exercices durant le jeu pouvait atteindre une haute intensité. **Participants:** Un total de 23 participants inactifs ont été recrutés pour jouer aux mini-jeux de Shape Up. la consommation d'oxygène (VO_2) , la fréquence cardiaque (FR) , et la dépense énergétique (DE) ont été mesurées avec un analyseur métabolique portable (K4b2 , Cosmed , It.

).**Résultats** : Les résultats sont présentés par moyenne ± écart-type , dans l'ordre suivant : jeu de squats ,jeu de pompes , jeu de course et jeu de boxe . Le %VO_2max pour les 4 mini-jeux était respectivement : 81 ± 12 % , 49 ± 17 % , 93 ± 13 % , et 60 ± 14 % et les METs moyennes pendant le mini-jeu était respectivement : 7 ± 1 METs, 4 ± 1 , 7 ± 1 METs et 5 ± 1 METs . **Conclusion** : Certains des mini-jeux sélectionnés sont des exercices d'intensité élevée (ex : squat et la course) et peut éventuellement atteindre les lignes directrices en activité physique pour un mode de vie actif.

7.3. Article

7.3.1. Energy expenditure and motivation while playing a new high intensity video game

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Energy expenditure and motivation while playing a new high intensity video game

Objective: The study goal was to determine if the new active video game, Shape Up (Ubisoft Montreal), can meet the minimal recommendations for a daily physical activity and if the intensity can reach a high-intensity. **Participants**: A total of 23 inactive participants were recruited to play at the mini-games in Shape Up. **Methods** Oxygen uptake (VO_2), heart rate (HR), and energy expenditure (EE) were measured with a portable metabolic analyser (K4b2, Cosmed, It.). **Results**: The results are presented by average ± standard deviation, in the following order: squat game, push up game, running game, and punch game. The % VO_2peak for the 4 mini-games was respectively: 81±12%, 49±17%, 93±13%, and 60±14%. and the average METs during the mini-game was respectively: 7±1 METs, 4±1 METs, 7±1 and 5±1 METs. **Conclusion:** Some of the mini-games selected are high intensity exercise (ex: squatting and running) and can possibly reach the physical activity guidelines.

Keywords: exergame, active video game, high intensity, ACSM physical activity guidelines

7.3.2. Introduction

According to the ACSM and CSEP guidelines (Garber et al. 2011; Tremblay et al. 2011), adults are encouraged to accumulate at least 150 minutes of moderate to vigorous aerobic physical activity per week. These guidelines are relevant to reduce the risk of premature death, coronary health disease, stroke, hypertension, some cancers, and osteoporosis and to improve fitness, body composition, and some mental health indicators (Garber et al. 2011; Tremblay et al. 2011). These guidelines also indicate that the 150 minutes can be done in bouts of 10 minutes or more and it is recommended in order to reduce the time spent engaging in sedentary behaviours, in particular screen-time activities like watching television, computer use, and playing video games.

To engage people as a fun and attractive form of exercise, an emerging type of active video game, the exergame, has emerged. Previous studies have investigated the energy expenditure and promote the health possibilities by testing these games on different populations such as children, overweight adults, and those needing rehabilitation (Biddiss and Irwin 2010; Peng, Crouse, and Lin 2012). However, many studies observe that the exergames didn't reach the physical activity guidelines and that the intensity was equivalent to light-to moderate intensity (Biddiss and Irwin 2010; Peng, Lin, and Crouse 2011). Despite these studies, it was possible to observe that some games reached an intensity similar to a traditional, moderate intensity physical activity (Peng, Crouse, and Lin 2012). This large difference in the intensity is mainly due to a difference in the gameplay and the device that was being used. Studies observing a small physiological effect used motion from a hand controller which only involved upper body movement. Furthermore, this device can allow the player to use a energy-saving strategy, where the movement can be performed only with the wrists when the game was designed to use the whole of the arms (Peng, Crouse, and Lin 2012). However, it is more difficult to use this strategy with a motion tracking, where all the body is being tracked, not only from a controller. Furthermore, this device can involve both the upper and lower body (Sinclair, Hingston, and Masek 2007; Taylor et al. 2012), and it has been observed that, gamest emphasized lower body movements had a higher energy expenditure and intensity than the games that mainly used the upper body (Biddiss and Irwin 2010; Peng, Lin, and Crouse 2011). Exergames offer more accessibility by removing certain reported barriers such as, the space needed, unsafe neighbourhoods, lack of transportation, seasonal condition, and mainly a lack of time due to the proximity and accessibility at any time at home (Biddiss and Irwin 2010; Godin et al. 1994).

The lack of time for exercise as the reason for not reaching the physical activity guidelines introduced an innovative exercise prescription such as High-Intensity Interval training (HIIT) (Gibala and McGee 2007). HIIT refers to repeated, relatively brief sessions, where the efforts are performed at close to maximum intensity (≥ 90% VO_2max) and, depending of the intensity, it may last from few seconds to up to several minutes. This effort is repeated and separated by up to a few minutes of rest or low intensity exercise (Gibala and McGee 2007). Previous studies have observed a remarkable improvement in exercise performance, cardiovascular fitness, exercise endurance, and blood pressure for this low volume training (Gibala and McGee 2008; Nybo et al. 2010). This HIT ability to improve certain physiological health markers for a low volume training makes this training an effective tool for promoting an active life (Nybo et al. 2010). However, the intensity of this training can be extremely hard on the motivation to tolerate the pain (Boutcher 2011). It is for this reason that the attractiveness, the fun, and the captivating activity of an active video game can help to compel the player to exercise (Sinclair, Hingston, and Masek 2007).

The purpose in this study was to determine whether the mini-games and workouts in a new active video game, Shape Up, can meet the minimal recommendations for a daily physical activity physique and if the intensity during the games can reach the minimum intensity to be used as a high-intensity, low volume training (HIIT). The hypothesis was that some mini-games such as the dance-step and punching games will have difficulty to succeed in reaching the minimum intensity for a daily physical activity like observed in previous games using the Wii console in previous studies (Biddiss and Irwin 2010; LeGear et al. 2016; O'Donovan et al. 2012), but the other mini-games had the potential to reach a high intensity due to their maximal repetition structure which recruits large muscle mass.

7.3.3. Methods

Participants

Twenty-two healthy adults (11 women and 11 men, aged 33±4 years) with an inactive lifestyle or low physical activity per week (<150 minutes of moderate to vigorous physical activity per week (Garber et al. 2011)) were recruited. The participants were recruited through a poster and invitation by emails via the social activity walls for employees within the company and were given the confidentiality clause of the game which was not announced during the project. Those with a cardiorespiratory disease, musculoskeletal injury, or other physical activity restrictions were excluded from participation. Ethics approval for this study was obtained by the University of Quebec at Montreal's Faculty of Science Research Human Ethics Committee, and a signed written consent form was obtained from all participants. The PAR-Q (Physical Activity Readiness Questionnaire), the heart rate, and the blood pressure at rest were also required before the tests according to CSEP (Canadian Society for Exercise Physiology) standards (CSEP/ SCPE 2003).

Testing Protocols

Physical Assessments

All participants were instructed about the tests' procedures and the exercise was demonstrated by the research team member at the start of every test. The movement was corrected if the participant did not execute the exercise correctly. A one repetition attempt was planned at the beginning of each test.

Anthropometry

The anthropometry was measured at the beginning of the assessment. The height (nearest 0.5 cm), weight (0.1 kg), circumferences (waist, hip, and buttocks), the % fat and % lean by ultrasound (bodymetrix, Intralametrix, USA) at the 7 sites (Jackson and Pollock 1985) was measured. The equation was as a function of the sex of the participant and the physical activity (inactive).

Cardiovascular fitness

The test was the sub-maximal, one step test with an imposed rate. The test had three stages at 18, 24, and 30 beats/min respectively. The stages was three minutes long each. The heart rate was taken at the end of each stage. The ACSM equation (ACSM 2010) was used to extrapolate the VO_2max of the participant. The heart rate was measured by a heart rate monitor (RS800, Polar, Fi) and the exhausted perception was also taken. A 5 minute cool-down was taken by the participant before the start of the next test.

Muscular endurance

The squat test was set as the mini-game structure to be able to easily compare the game with the fitness assessment; the three sets were 25, 20, and 15 seconds of squatting with a rest of 15 seconds between each set. The instructions given to the participants were to do as many squats as they could during the three sets. The research team member indicated the start and end time. The participants were informed that if the squat did not correspond to exigency (down to knees at 90 degrees, the body-weight on the heels and a straight back) it did not count. The total was noted.

The push-up test was set as the mini-game structure to be able to easily compare the game with the test. The test was five sets of 15 seconds each with five seconds of rest between each set. The instructions given to the participants were to do as many push-ups as they could during five sets of 15 seconds. During the rest of five minutes they could stay in plank position or stay on the floor (the same as in the game). The participant was informed that the push-up had to be conform as the CSEP guidelines (CSEP/ SCPE 2003), and if it was not, it did not count. The women did the push-ups on their knees and the men on the feet. The heart rate had to be less than 100 beats/minutes before the participant could leave

Video Game activities

The game training period lasted a total of 20 minutes and it was constituted of various sessions made of four mini-games chosen from a possible 5, that were two to three minutes in duration, and 2 workouts of around five minutes (6 games in total) from the game Shape-Up (Ubisoft Divertissement, Montréal). Figure 7.1 gives a summary of the game. Briefly, the mini-games were composed of simple movements (running on the spot, boxing, push-ups, and squats) where they need to be try as much as possible and a mini-game with a dance step gameplay, and the workouts were performed in the presence of the virtual coach. However, workout and dance step's gameplay also include few seconds where the player needs to maximally perform punching or running on spot. Between each of the mini-games and workout there was a 1-2 minute rest period that was shown by the uploading and presentation of game's results. Two sessions with different order and selected mini-games were distributed into semi-random order. The energy expenditure, the oxygen uptake, the heart rate, and the ventilation were measured by the breath-by-breath metabolic analyzer (k4b2, Cosmed, It) and the heart rate monitor (T1, Polar, Fi) during all the sessions. The exhausted and fun perceptions were also taken at the end of the mini-games and the workout. The numbers of squat and push-up repetitions in the mini-games were measured and they needed to reach the same standard as in the assessment in order to be counted. The heart rate had to be less than 100 beats/minutes before the participant could leave. The game was in the pre-alpha phase and needed the presence of an expert to assist with the gameplay.

Data Analysis

The data were analyzed with the software SPSS 12. The data from the metabolic analyzer was filtered every five seconds. The results were presented in mean ± standard deviation form. A paired T-test was used to compare the total number of push-ups and squats during the fitness assessment and the game.

7.3.4. Results

The twenty-two participants complete the physical assessment test and the video game session. Table 7.1 shows the participant's descriptive characteristics. The low VO_2max extrapolated shows the inactive level of the participants. Table 7.2 shows the measurement during the different games.

All mini-games and workouts reached the minimum of 3 METS (moderate intensity activity, the minimum required for physical activity by the ACSM (Garber et al. 2011). The push-up and punching mini-games are the only games with less than 50% of the duration at a vigorous intensity ($\geq$6 METS), however the majority of the time is still above the minimum intensity recommended by the ACSM (3 METS)(Garber et al. 2011). The energy expenditure reached around 145 kcal for the active time of the session (less than 20 min), where the oxygen uptake average is around 70% of the VO_2max extrapolated.

Furthermore, the number of push-up and squat repetitions was significantly higher during the game than during the assessment in the gym with the same structure and instructions. The number of push-ups in the gym was 25±11, whereas during the game it was 34±11 ($p=0.00$) and the number of squats in the gym was 47±8 and during the game it was 59±7 ($p=0.00$).

The primary goal of this study was to quantify the energy expenditure during the games and determine if the intensity of Shape Up games can reach the daily recommendation for physical activity. All across games (mini-games and workouts) the intensity was higher than 3 METS (moderate intensity) and for most of them it was higher than 6 METS (vigorous intensity). To our knowledge, it is the first time that an active video game has reached such intensity as an average for an active video game. Furthermore, this finding suggests that such games could be used by high-intensity, low volume training for inactive people in order to promote physical activity and increase their health benefits.

Exergames and physical activity guidelines

Previous studies with active video games showed a low or moderate intensity, ranging from 2.0 to 5.0 ± 3.3 (Biddiss and Irwin 2010). Furthermore, playing active video games across a range of ages seems to show a slightly lower energy expenditure with adults compared to children (Sell, Lillie, and Taylor 2010). For this reason, it is recommended to not use active video games as a replacement for vigorous physical activity, but rather for increasing the total energy expenditure for inactive people (Graves et al. 2007). The energy expenditure in active video games is highly variable and depends on the muscle recruitment. Biddiss and Iwin (2010) explain that a motion controller active video game relies primarily on movements of upper body and induces a mean percentage increase in energy expenditure of around 116% from rest. However, for a dance step platform, like *Dance Dance Revolution* (DDR), which mainly involves the lower body (bigger muscles recruitment) the mean percentage increase in energy expenditure is 212%. The difference between different controllers was corroborated by (O'Donovan et al. 2012) where the authors explained that not only a lower muscle mass is implicated with a motion controller- active video game, but also the possibility of using an energy-saving way to succeed in completing the goal of the game only using wrist movement instead of the entire arm. In the present study the active video game uses motion capture (Kinect) and allows the player to use both the upper and lower body for the task demanded and therefore it recruits more muscle mass. It is not only for this reason that it is possible to reach a high intensity, but also due of the maximum repetition goal in the mini-games compared to an imposed rhythm like the majority of active video games' gameplay. This ''all-out'' effort possibly allows an inexperienced gamer, by simple movements, to reach a high intensity. This corroborates a previous study (Sell, Lillie, and Taylor 2010) where experienced exergames players can reach a higher intensity due to the possibility of going at a fast speed than the inexperienced players. were the complexity of the game and the intensity imposed was a barrier in reaching a high intensity exercise. The present game shows moderate to vigorous intensity during most of the game duration and can reach an extrapolated maximum intensity. This is an important characteristic in order for the game to be a tool for high intensity, low volume training. Furthermore, the participants were so motivated by the game that they performed more repetitions in the squat and the push-up games than during the assessment in the gym, where the requirements were the same. Possibly due to the attractiveness of the gameplay, as explained by Sinclair, Hingston and Masek (2007), the players reach the recommended duration and recommended frequency due to the fun and captivating exercise. To reach these recommendations the ACSM guidelines and CSEP guidelines recommend at least 150 minutes per week of moderate to vigorous intensity of physical activity or to achieve a total of ≥500-1000 METS*min*week. (Garber et al. 2011; Tremblay et al. 2011). The present game, Shape Up, can reach this standard by playing 7-8 sessions per week that are already built into the game, including 4 mini-games and 2 workouts, or by playing the running game, the squat game, and/or the workouts for a minimum 63 to 71 minutes per week depending on the combination of the games. Active video game have the advantages of being easy to use and quite accessible to have at home (less space, relatively low cost, etc.) combined with requiring less time to reach the minimum physical activity for health benefits due to the high intensity of the running and squat mini-games, and the workout.

HIIT (characteristics vs this study and benefits)

A high intensity, low volume training can induce important benefits, such as an improvement in a small amount of time of cardiovascular fitness, exercise endurance, glucose tolerance, and lowering the blood pressure (Burgomaster et al. 2005; Gibala and McGee 2008; Gillen and Gibala 2014; Nybo et al. 2010). This improvement in various physiological health parameters interested researchers to use it for promoting an active lifestyle. Generally, the structure for this training is composed of high intensity repetitions (≥90% VO_2max) for few seconds to few minutes separated by a few minutes of rest or low intensity exercise at a low volume over a week (Gibala and McGee 2008). The present study shows a similar intensity, where for few seconds the participants reached an intensity ≥ 90% of their extrapolated VO_2max for the running game and the cardio workout, and close to 90% for the squat game, the dance step, and the muscular workout. Even if the other games cannot reach a high intensity, it can be possible to use them as an active recovery exercise in the intervals between high intensity exergames. The present study shows a similar performance during the entire game as the protocol of the high intensity training of Nybo et al. (2010). In that study the interval was around 2 minutes of high intensity; above 95% of the extrapolated maximal heart rate (running, squatting, and dance step mini-games, and the 2 workout) followed by low intensity games (boxing and push-up games). The present study seems to show similar characteristics of a high intensity training and the Shape Up game seems to be a potential tool for promoting an active life style. As proposed by Gibala and McGee (2008) the lack of time is the most commonly cited reason for not exercising and is a potentially valuable reason to promote this innovative training to help the population to have an active lifestyle. Furthermore, the structure of this training can help with the adherence not just because of the time required, but also because of the engagement of the player. Indeed, it seems that the adherence improves with low frequency and high intensity rather than high frequency and low intensity (King et al. 1997). Furthermore, HIT is often dismissed due to the intolerable intensity of the game (Boutcher 2011; Gibala and McGee 2008), however the attractiveness characteristic from the ''flow'' of the active video game, as explained by (Sinclair, Hingston, and Masek 2007) seems to play an important role for the motivation of the player, where the player focuses and delves deeply into the game. As observed in the present study the participants seemed to forget the unpleasant discomfort from the maximal exercise during the game and they produced more repetitions than in the gym environment.

Limitations

The primary limit of this study is the absence of an intervention in order to evaluate the training effect of the game and the adherence during a longitudinal study. Furthermore, the participants were in a research environment and it is possible that a home environment can have a different effect on the motivation. However, it is also possible that this situation has an inverse effect, where the participant was shy too play in front of the research group, therefore decreasing their performance. In general, the participants really enjoyed their experiences and they participated in another study where they played the game for 6 weeks; the results of that research will be published in a paper in production.

7.3.5. Conclusion

The new, innovative, high intensity active video game, Shape-Up, seems to have the potential to be used as a high intensity interval training using the modality provided by some mini-games (squat, dance step, and running) and the workouts. Furthermore, the motivation and the pleasure from using this game can help to improve the exercise intensity experienced, where the number of squat and push-up repetitions was higher during the game than in gym. However, further investigation will need to be done to observe the adherence of this game in an ecological environment.

7.3.6. Acknowledgements

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Disclose professional relationships with Ubisoft for this study. The results of the present study do not constitute endorsement by ACSM. The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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7.3.8. Tables

Tableau 7.1: Participant's characteristics

Caracteristics	Mean±SD
Age (years)	33±4
Weight (kg)	73.5±13.3
Height (cm)	172±7
BMI (kg/m²)	24.8±3.5
VO_2 max extrapolated (ml/kg/min)	32.7±4.7

Table 7.2:Measurements during the game

	Running	Boxe	Squat	Push-up	Dance step	Cardio-workouts	Muscular-workouts
METS average	7±1	5±1	8±1	4±1	6±1	8±1	7±1
METS peak	9±2	6±2	7±1	5±1	8±2	9±2	8±1
% time at 3-5.9 METS	10±13	77±30	35±30	90±10	45±31	15±17	29±31
%time at $\geq$6 METS	90±13	18±30	65±30	4±9	55±31	85±22	71±32

Energy expenditure total (Kcal)	15.9±4.2	9.9±4.1	15.1±4.7	11.7±4.1	12.7±2.4	37.9±10.6	32.8±9.0
VO_2peak (ml/kg/min)	30.8±5.7	19.9±5.6	27.1±4.7	18.3±2.6	27.2±6.3	33.0±5.3	28.4±5.0
%$VO_{2max\ ext}$ peak	99±14	60±14	81±12	54.0±5.9	86±18	100±12	86±11
VO_2 average (ml/kg/min)	25.8±4.4	16.6±4.6	23.1±3.3	15.0±2.2	22.6±4.2	27.9±4.3	24.2±4.2
%$VO_{2max\ ext}$ average	79.5±13.4	50±12	70±10	44.2±5.7	71±12	85±10	73±10
Number of repetitions	-	-	59±7	34±11	-	-	-

Heart rate peak (bpm)	179±21	149±16	170±12	160±13	157±17	175±9	179±9
Heart rate average (bpm)	166±29	138±17	164±13	150±11	142±19	164±11	171±10
OMNI cardio	7±1	3±2	7±2	6±3	4±1	7±1	9±1
OMNI muscular	5±3	2±2	6±2	9±2	3±1	4±2	8±2
Pleasure during the game (/10)	6±1	7±2	6±2	5±3	6±1	7±1	7±1

7.3.9. Figures

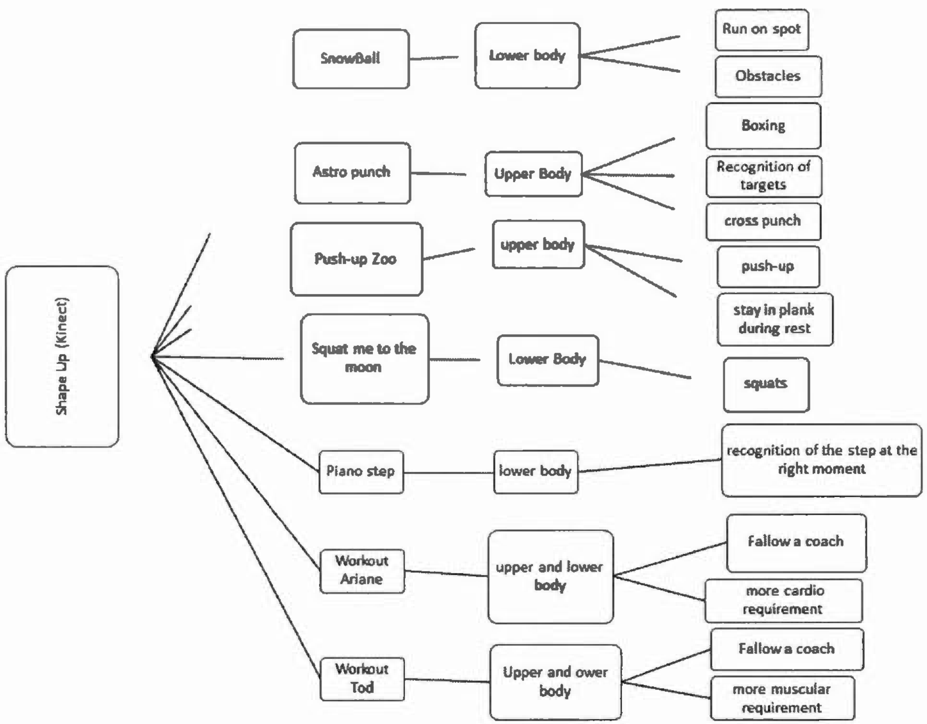

Figure 7. 1: Explanation of the mini-games and Workout

CHAPITRE VIII: UTILISATION DE LA NOUVELLE MÉCANIQUE DE JEU VIDÉO ACTIF SUR 6 SEMAINES

8.1. Mise en contexte

Le dernier chapitre présentait l'intensité très élevée du nouveau jeu vidéo actif, par contre il n'était pas possible de mesurer l'impact d'un tel entraînement comparé à un entraînement traditionnel. Le présent chapitre observe les changements dans la condition physique chez des personnes inactives d'un entraînement de 6 semaines à l'aide du jeu vidéo actif en comparaison à des personnes inactives débutant un programme d'entraînement traditionnel pour la même durée. Selon les études sur l'entraînement par intervalle de haute intensité où la structure est similaire au nouveau jeu vidéo actif, les participants devraient s'améliorer davantage dans un cours intervalle de temps et pour un temps d'entraînement par semaine moindre.

8.2. Résumé

Selon les recommandations de la Société canadienne de physiologie de l'exercice (SCPE) et l'American College of Sports Medicine (ACSM), au moins 150 minutes par semaine d'activité physique modérée sont nécessaires pour maintenir un mode de vie sain. Cependant, peu d' adultes atteignent ces recommandations . Un nouveau jeu vidéo actif , Shape Up (Ubisoft, Montréal) veut initier la pratique de l'activité physique en motivant par son aspect ludique. L'objectif de l'étude était d'évaluer la capacité d'un jeu vidéo pour produire des améliorations des capacités physiques. Un total de 22 participants (11 femmes et 11 hommes, 33 ± 4 ans) pratiquant moins de 150 minutes d'activité physique par semaine ont été recrutés pour participer à l'étude,

incluant une évaluation de la condition physique avant et après le programme d'entraînement. Les participants se sont engagés à 60-90 min (45-60 min d'exercice actif) par semaine pendant 5 semaines d'activité physique guidées par une plateforme de jeu vidéo basé sur Kinect. Les mesures pré et post-entraînement comprenaient 1) la composition du corps, 2) la capacité aérobie, et 3) l'endurance musculaire. Des améliorations significatives ont été observées dans les trois composantes: 1) une diminution du % de gras corporel (11,2 ± 8,0%, p = 0,01),et des circonférences de la taille (6,0 ± 2,7%, p = 0,01), de la hanche (5,8 ± 3,4%, p = 0,01), et les fesses (3,3 ± 1,7%, p = 0,01) ; 2) une augmentation de la capacité aérobie de 12,1 ± 11,4% (34 ± 4,8 vs 38 ± 6,0 ml/kg/ min, p = 0,01); et 3) de l'endurance musculaire des membres supérieures (pompes) et inférieures (squats) a augmenté de 111 ± 102% (p = 0,01) et 44,1 ± 25,5% (p = 0,01), respectivement. En conclusion, il semble que 45-60 minutes par semaine pendant 5 semaines d'exercice à haute intensité (70-90% FCmax) modulé par une plate-forme de jeu vidéo basé Kinect est suffisant pour induire des changements importants dans la composition corporelle, la capacité aérobie, et de l'endurance musculaire

8.3. Article

8.3.1. Title: Physiological changes after a 6 week training program with a High Intensity Exergame

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8.3.2. Abstract

According to the recommendations of the Canadian Society for Exercise Physiology (CSEP) and the American College of Sports Medicine (ACSM), at least 150 minutes per week of moderate physical activity are required to maintain a healthy lifestyle, however, few adults reach these recommendations. Active video games, such as Shape Up (Ubisoft, Montreeal) want to promote the practice of physical activity in a more playful, motivating way. Thus, the goal of the study was to assess the ability of a video game to produce beneficial physical fitness changes. A total of 22 participants (11 women and 11 men, 33 ± 4 years) practising less than 150 minutes of physical activity per week were recruited to take part in the study and a prior physical fitness evaluation. The participants engaged in 60-90 min (45-60 min active exercise) per week for 5 weeks of physical activity guided by a Kinect based platform video game. Pre- and post-training measurements were gathered for 1) body composition, 2) aerobic capacity, and 3) muscle endurance. Significant improvements were seen in all three components: 1) a decrease in percent body fat (11.2±8.0%, p=0.01), waist (6.0±2.7%, p=0.01), hip (5.8±3.4%, p=0.01), and buttock (3.3±1.7%, p=0.01) circumferences; 2) an aerobic capacity increase of 12.1±11.4% (34±4.8 ml/kg/min vs. 38±6.0 ml/kg/min, p=0.01); and 3) upper (push-ups) and lower (squats) muscle endurance increases of 111±102% (p=0.01) and 44.1±25.5% (p=0.01), respectively. In conclusion, it appears that 45-60 min per week for 5 weeks of medium to high intensity (70-90% HRmax) exercise modulated by a Kinect based platform video game is sufficient to bring about significant changes in body composition, aerobic capacity, and muscle endurance in previously inactive individuals.

Key Words: active video game, ACSM physical activity guidelines, active lifestyle, fitness improvement, physical activity promotion

8.3.3. Introduction

An inactive lifestyle and related metabolic-disorders are becoming an expanding and important health problem in modern society (Booth et al. 2000). In accordance with the American College of Sport of Medicine a minimum of 150 minutes of moderate physical activity per week are required to maintain a healthy lifestyle (Garber et al. 2011). The Center for Disease Control and Prevention, as well as the Committee on Exercise and Cardiac Rehabilitation of the American Heart Association and the Canadian Society for Exercise Physiology have endorsed and supported these recommendations in their guidelines in order for a healthy adult to improve and maintain health (Haskell et al. 2007; Tremblay et al. 2011). However, ''lack of time'' is the most commonly cited reason to not reach the physical activity guidelines (Godin et al. 1994). Accumulating evidence suggests that High Intensity Intermittent Exercise (HIIE) is a possible solution for effective and time economic exercise in order to maintain and improve health.

HIIE, or also called high-intensity interval training, generally refers to a repeated brief intermittent exercise performed at the maximum, or close-to-maximum, intensity which elicits a peak oxygen uptake (VO_2 peak) of $VO_2 \geq 90\%$. The effort may last from a few seconds to up several minutes depending on the training intensity, where the multiple efforts are separated by up to a few minutes of either rest or low intensity exercise (Gibala and McGee 2008). This very low volume and very high intensity training, when done for a short period of time, induces an improvement in the VO_2peak, maximal activity of mitochondrial enzymes in skeletal muscle, metabolic adaptations, and subcutaneous and abdominal fat loss (Boutcher 2011; Gibala and McGee 2008; Nybo et al. 2010). The benefits of HIIE on health parameters for a shorter time per week of physical activity than the traditional exercise given in many in physical activity guidelines could be a time-efficient strategy for health promotion (Gibala 2007; Nybo et al. 2010). However, most of the protocols are extremely hard and subjects have to be highly motivated to tolerate the accompanying discomfort (Boutcher 2011), which can degrade the enjoyment and possibly the adherence in long term. Previous studies show that the use of active video games can give more enjoyment than a traditional workout, like using the treadmill, and possibly play a role in the adherence of an active life, but this requires further exploration (Biddiss and Irwin 2010; Sell, Lillie, and Taylor 2010).

Active video games, dubbed as ''exergames'', are controversial for use in reaching physical activity guidelines (Biddiss and Irwin 2010; Peng, Crouse, and Lin 2012). However, previous studies observe, in general, that active video games produce a moderate intensity physical activity and have a good potential to improve aerobic fitness (Biddiss and Irwin 2010; Peng, Crouse, and Lin 2012; Sell, Lillie, and Taylor 2010; Smallwood et al. 2012). Furthermore, studies that observed smaller effects used an active video game that involved mainly the use of the upper body and used a motion tracking controller (like the Wii system), where it is possible to use energy saving strategies (Peng, Crouse, and Lin 2012). A new platform, such as the Kinect, uses motion capture to track all of the body and can induce more energy expenditure than a controller-based motion tracking game (Parent, AA. et al., submitted paper). Furthermore, a new game, Shape Up, uses a high-intensity, intermittent exercises structure, where the player needs to give their maximum effort to complete the game. Shape-up induces an intensity that was not observed for an active video game to the best of our knowledge (Parent, AA. et al., submitted paper). Thus, the aim of this study was to observe the physiological fitness changes after 6 weeks of training with a new active video game, Shape Up, with a low volume, high intensity intermittent exercise structure compared to a traditional training at the gym.

8.3.4. Methods

Participants

Thirty-one healthy adults (13 women and 18 men, aged 33±4 years) with an inactive lifestyle or low physical activity per week (<150 minutes physical activity per week) were accepted to participate to the study. Twenty-one (11 women and 10 men) were recruited for the active video game group and ten (2 women and 8 men) for the traditional training. The participants were recruited through a poster and invitation emails on the social activity walls of their place of employment and the employees were given the confidentiality clause of the game which was not announced during the project. Those with a cardiorespiratory disease, musculoskeletal injury, or other physical activity restrictions were excluded from participation. Ethics approval for this study was obtained by the University of Quebec at Montreal's Faculty of Science Research Human Ethics Committee and a signed written consent form was obtained from all participants. The PAR-Q (Physical Activity Readiness Questionnaire), the heart rate, and the blood pressure at rest were also required before the tests according to CSEP (Canadian Society for Exercise Physiology) standards (CSEP/ SCPE 2003). Two women from the active video game (9.5%) and one men from the traditional training (10%) withdrew for time reasons, where they missed more than 2 sessions. Moreover, it was more difficult recruiting for the traditional training group than the active video game group and this explains the smaller sample.

Procedures

The procedure has been described in detail elsewhere (Parent et al. submitted). Briefly, the fallowing procedure was describe in a previous paper (Parent et al. in submission)

Physical Assessments

All participants were instructed about the test's procedures and the exercise was demonstrated by the research team member at the start of all tests. The movement was corrected if the participant did not execute the exercise correctly. A one repetition attempt was planned at the beginning of each test.

Anthropometry

The anthropometry was measured at the beginning of the assessment. The height (nearest 0.5 cm), weight (0.1 kg), circumferences (waist, hip, and buttocks) was measured using standard procedures (CSEP/ SCPE 2003), while the % fat and % lean body mass was measured by ultrasound (BodyMetrix, Intelametrix, USA) using 7 sites (Jackson & Pollock). The equation was as a function of the sex of the participant and the level of physical activity (inactive).

Cardiovascular fitness

The test was the submaximal, one step test with an imposed rate. The test had three stages at 18, 24, and 30 beats/min respectively. The stage was three minutes long each. The heart rate was taken at the end of each stage. The ACSM equation (ACSM 2010) was used to extrapolate the VO_2max of the participant. The heart rate was measured by a heart rate monitor (RS800, Polar, Fi) and the exhausted perception, by OMNI scale, (Aamot et al. 2014) was also taken. A 5 minute cool-down was taken by the participant before the start of the next test for muscular endurance.

Muscular endurance

Lower body muscle endurance was composed of three sets of 25, 20, and 15 seconds of squats with a rest of 15 seconds between each set. The instructions given to the participants were to do as many squats as they could during the three sets. The research team member indicated the start and end time. The participants were informed that if the squat did not correspond to the requirements, i.e., knees flexed at 90 degrees, the body-weight on the heels and a straight back, the squat did not count. The total number of squats was noted.

Upper body endurance consisted of five sets of 15 seconds each with five seconds of rest between each set. The instructions given to the participants were to do as many push-ups as they could during five sets of 15 seconds. During the five minute rest period they could stay in plank position or stay on the floor (the same as in the game). The participant was informed that the push-up had to be conform to the CSEP guidelines (CSEP/ SCPE 2003) and if it was not conform then it did not count. The women did the push-ups on their knees and the men on the feet. The heart rate had to be less than 100 beats/minute before the participant could leave.

Flexibility test

A modified Sit and Reach test measured by a sit-and-reach box (Flex-Tester, Novel Product, IL, USA) was then performed. The protocol of the test was according to the CSEP fitness assessment (CSEP/ SCPE 2003). The best of three measures was noted.

Effort perception

At the end of the cardiovascular test and muscular endurance tests, the effort perception was measured with an OMNI scale.

Video Games training

The participants played a total of 60 to 80 minutes per week, with an obligatory 60 minutes/week, however they had the possibility to continue for a total of 80 minutes over two sessions during a week for 6 weeks. It is important to note that the 60 minutes included the games' loading time (passive rest for the player), the active time was around 30 minutes. However, the participants were allowed to miss a maximum of 2 sessions during the program (for a minimum of 5 weeks of training). The exercise intensity was measured in a previous study (Parent et al.. in submission) and was around 6 METS. The number of repetitions of squat and push-up during the game were counted. The exercise was to be executed according to the norm to be counted (norm's references). The exhausted perception (OMNI) and fun perception were also taken using an Omni scale. The participants were monitored with a heart rate monitor (RS800, Polar, Fi) and it was set to measure the heart rate every 5 seconds during each session, the heart rate measured was between 70-90% of the predicted maximal heart rate. A kinesiologist was present to note the results, follow up the training, and ensure the safety of the participants. Furthermore, the game was in the pre-alpha phase and needed the presence of an expert to assist with the gameplay. The fig. 9.3-1 show the mini-game sequence.

Traditional training

The participants trained for 3 sessions per week for around 1 hour a session at the gym for 5weeks in order to reach the ACSM guidelines of a minimum of 150 mins/week of moderate to vigorous physical activity. However, the participants were allowed to miss a maximum of 2 sessions during the program (for a minimum of 5 weeks of training). The training was composed of cardiovascular interval training where a 5 minute warm-up was followed by 7 to 8 intervals of 1 minute training at 85-90% of the predicted maximal heart rate. 30 seconds of active rest (walking), and finally 5 minutes of inactive rest. The session was also composed of a muscular training part where the participants had a circuit of squats, chest presses, rowing-machine, and sit-ups for 3 series of 12 repetitions. The session ended with a flexibility exercise. The program was not assisted by a personal trainer, however a coach was available in the gym to answer questions or help the participants during their training.

Data Analysis

The data were analyzed with SPSS (ver. 21). The results are presented as mean ± standard deviation. A paired T-test was used to compare pre- vs post- measurements by sex and a two-way analysis of repeated-measure ANOVA were used to calculate differences between and within the groups.

8.3.5. Results

The participant's characteristics are presented in Table 8.1. The participants were inactive, however their BMI were in the normal-overweight category and they didn't have important limit to physical activity.

Table 8. 1: Participants Characteristics

	Active Video game group		Traditional training group	
	Women	Men	Women	Men
Height (m)	1.67±0.05	1.79±0.07	1.65±0.14	1.76±0.09
Weight(kg)	69.0±7.5	84.3±16.6	60.5±10.2	77.0±7.9
IMC (kg/m^2)	24.7±1.8	26.2±4.4	22.3±0.1	24.9±3.0

The intervention measurements are presented in Table 8.2 and were analyzed with a paired T-test for both women and men separated and together given the sample size. However it seems important to show women and men separately due to the differences between sexes. A non-significant effect was found between the two groups except for the %fat (p=0.044).

Table 8. 2:Pre vs post intervention

	Pre-Active Video game		Post-Active Video game		Pre-traditional training		Post-traditional training	
	Women	Men	Women	Men	Women	Men	Women	Men
% fat (%)	35±3	22±5	33±3	19±5*ǂ	31±1	19±2	28±1	18±3*ǂ
Waist circumference (cm)	79±8	89±10	74±6*	79±19*ǂ	72±3	85±6	67±4	82±6*ǂ
Aerobic capacity								
$VO_{2\ max\ extrapolated}$ (ml/kg/min)	32±4	35±5	35±4*	40±7*ǂ	32±0	43±4	33±4	40±5
Muscular endurance								
Squat (nb)	45±8	48±9	63±8*	68±9*ǂ	44±13	64±14	43±12	64±13

Push-up (nb)	21±11	27±12	43±10*	43±14*[ı]	35±9	33±14	48±18	38±16[ı]
Sit and reach (cm)	24±11	18±11	27±10*	25±13[ı]	33±13	19±11	35±11	21±12
Effort perception								
OMNI aerobic test	5±2	5±2	4±3[ı]	5±2	4±4	4±2	4±1	4±1
OMNI squat	5±1	5±1	5±2	6±2	4±0	6±1	5±0	6±2
OMNI push-up	9±1	10±1	8±2	9±1	9±1	9±1	9±1	9±1

*significant difference $p \leq 0.05$
[ı] Significant difference without sex differentiation $p \leq 0.05$

Anthropometry: The active video game group, for women ($p=0.002$) for men ($p=0.046$), and both sex together ($p=0.005$), significantly decreased their waist circumference pre- vs post- intervention. However, the %fat was only significant for men, when the sex are analyzed separately ($p= 0.308$ for women and $p=0.029$ for men), and significantly lower ($p=0.016$) when the group is analyzed all together. A similar finding was observed for the traditional training group, where the men have significantly decreased their %fat and waist circumference ($p=0.006$ and $p=0.008$ respectively, and for the group together $p=0.006$ and $p=0.001$ respectively). However, the sample size of women for the traditional training group is very low and it is insufficient to observe a significant difference.

Cardiovascular capacity: Only the active video game group showed a significant difference pre- vs post- intervention. With and without sex differentiation, the extrapolated VO_2max increased after the intervention ($p=0.040$ for women and $p=0.029$ for men and $p<0.001$ together). However, the training group did not show a significant difference, and it also seemed that the men unperformed at the assessment.

Muscular capacity: The muscular capacity increased significantly for the active video game group, the number of squats, push-ups, and flexibility significantly improved also ($p=0.000$ for the push-ups and squats, and $p=0.016$ for the flexibility test). However, the traditional training group did not show a significant difference between pre- and post- intervention, except for the push-ups ($p=0.039$).

Effort perception: The effort perception did not change significantly except for the aerobic sub-maximal test where the active video game group perceived less ($p=0.017$), possibly because it is the only test that did not require a maximum effort.

8.3.6. Discussion

This goal of the present study was to quantify the fitness adaptation after 6 weeks using different interventions: an active video game with a high-intensity, intermittent exercise structure and a traditional training. To our knowledge it is the first time that an active video game had a high-intensity structure, mainly due to the difficulty in being able to reach a high intensity level with previous active video games. The main finding was a significant improvement of the cardiovascular aptitude, muscular endurance, flexibility, and anthropometric assessment results after 6 weeks of active video game during 60 to 80 min/week. Furthermore, the traditional training group only improved significantly for the anthropometric assessment and push-up tests after the intervention with a bigger volume (150 mins/week of moderate to vigorous physical activity).

High intensity training benefits

A low volume, high-intensity training seems to show a better adherence than a high frequency and low intensity (Gibala 2007). As an alternative, it is possible to do a high-intensity exercise for a short amount of time (few minutes) often during the week and integrate it into daily life. For example; previous studies used short bouts of stair climbing (Boreham, Wallace, and Nevill 2000; Boreham et al. 2005), where the VO_2max and a lower density lipoprotein cholesterol were observed after only 8 weeks (Boreham et al. 2005). Among the benefits from this training structure, time vs health improvement is an important factor when time is an important barrier for most people that want to have an active life (Godin et al. 1994). In the present study, the adherence was the same for both groups, with 10% lost in each group. However, the intervention was only 6 weeks and so further research will need to be done to observe the adherence during a period of time beyond 6 weeks. Moreover, a short, high intensity exercise observed earlier fitness improvement, with as little as 2 weeks; previous studies observed an aerobic performance improvement, increased VO_2max, and increased lipid sensitivity (Burgomaster et al. 2005). These results corroborate the present study where significant improvement was observed after a short period of time (6 weeks) in the active video game group while the traditional training will presumably need more time to observe significant improvement. Quick improvement in a short amount of time during the week can be the solution for many inactive people wanting to change their habits, where one of the factors is to measure their improvement in order to continue an active life(Backhouse et al. 2007). High intensity training studies observed other benefits such as producing a significant increase in anaerobic fitness, significant skeletal muscle adaptations, subcutaneous and abdominal fat loss, and reduce arterial pressure (Boutcher 2011; Gibala 2007; Gibala and McGee 2008; Nybo et al. 2010). These fitness improvements corroborate many observations in the present study, emphasising on the potential benefits of the present active video game tool in order to obtain health benefits from a low volume of physical activity. Finally, a physical activity that can induce a perception of High-Activity and pleasure seems to induce an experience with positive engagement, positive well-being, vigour, and revitalization (Backhouse et al. 2007). It is what the present active video game study tries to reach this intensity, observing a ''very intense'' effort perception. However, further investigation will need to be done to observe the impact on a long-term duration.

Active Video Game training (exergaming)

An important factor is the engagement of the player when there is physical activity aspect of the game. Previous studies show the pleasure and the engagement of people is an important factor in the adherence, continuation and the amount of physical activity on a daily base (Sell, Lillie, and Taylor 2010). Controller-based exergames are also presented as an easy accessible way to improve the energy expenditure in general (Biddiss and Irwin 2010; Smallwood et al. 2012). However, it is not recommended to use these games to achieve the physical activity recommendations due to the low intensity induced by these games. (Biddiss and Irwin 2010). Despite the recommendations, the present study showed fitness improvement using the active video game's high-intensity structure. Furthermore, the previous studies on active video games mainly used a motion controller, tracking the controller by the hand and at the same occasion using a game that involved upper body movement (Peng, Crouse, and Lin 2012). This game design induced a lower energy expenditure than games that involved lower body movement (Biddiss and Irwin 2010; Peng, Crouse, and Lin 2012). Furthermore, the player using a motion controller can use an energy-saving strategy, by moving the wrist instead of the arms to succeed in the game (Peng, Crouse, and Lin 2012). Previous studies generally did not observe significant changes in physiological outcome, where the focus was on weight or body mass loss (Biddiss and Irwin 2010). However, the present study showed important benefits in anthropometric measurements and fitness measurements. This is possibly due to the intensity of the game, which was an exergame was generally associated to light to moderate intensity in previous studies (Garber et al. 2011). While in the present game the intensity observed was moderate to vigorous, which was performed with an "all-out'' effort with peak intensity close to maximum. The mini-games were structured to make the player do as much as they can and so that they do not have to follow a pace imposed by the game; this structure can help to reach higher intensity. Furthermore, this game reached the four key design technology requirements that encourage physical activity (Consalvo 2006): 1) Give the user proper credit for the activities, when they do as much as they can (maximal repetition), 2) Provide personal awareness of their activity level, where the player can see their progression for the physical activity done and number of repetitions performed in order to beat their best performance, 3) Support social influence, where the players can play with a friend or send one of their performances and 4) Consider the practical constraints of users' lifestyles, where the possibility to do physical activity at home, without a large space requirement or important equipment can facilitated the access to an active lifestyle, without the time efficiency of the game structure where the main reason for being inactive is the time constraint(Stutts 2002), making a precious tool for promoting an active lifestyle. However, more investigation will need to be done in order to observe if similar observations can be translate to the home environment and for the long-term adherence.

Physical activity Guidelines

The present ACSM guideline and CSEP guidelines for physical activity recommendations require people to accumulate at least 150 min/week of moderate- to vigorous-intensity aerobic physical activity or at least an accumulated 500-1000 MET*min*week^{-1}. The present study shows that with only 60 min a week (including rest time during game's loading time) and in only 6 weeks the anthropometric, cardiovascular, and muscular capacities improve for inactive people. However, playing 63 to 125 min/week depending on the mini-game, people can reach the guidelines of 500-1000 MET*min*week^{-1} and they can possibly increase their physiological capacity (Parent et al. in submission). However, the present study shows that with less time spent on physical activity it is possible to further improve fitness parameters, corroborating previous studies, where, in a short period of time and low volume, fitness parameters such as cardiovascular fitness, glucose tolerance, blood pressure and muscle adaptation improve (Gillen and Gibala 2014; Nybo et al. 2010)

Limits and Perspective

Like any equipment at home, it cannot give the participant motivation like an appointment with a coach or a partner. The study was made to be like an appointment structure and that will perhaps help with the adherence. However, the participants wanted to continue after the study, which shows the will to continue to use it. It can be important to create a virtual coach or to use the online friend challenges to keep the participant motivated to play and to keep the adherence in the long-term. Furthermore, the game needs to provide new content to not only break the monotony and increase the motivation, but also for the improvement of physiological capacity. Further ecological, home based, investigation needs to be done over the long-term to observe the adherence of this possible new tool to promote physical activity.

8.3.7. Conclusion

In conclusion, the present study investigated fitness measurements after 6 weeks of playing a very intense active video game at low volume compared to a traditional training. The improvement with the active video game group was observed as the cardiovascular fitness, muscular endurance, flexibility, and anthropometric measurements improved. This emphasizes the potential health benefits to use this tool in order to promote physical activity.

8.3.8. Acknowledgement

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Disclose professional relationships with Ubisoft for this study. The results of the present study do not constitute endorsement by ACSM. The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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8.3.10. Figures:

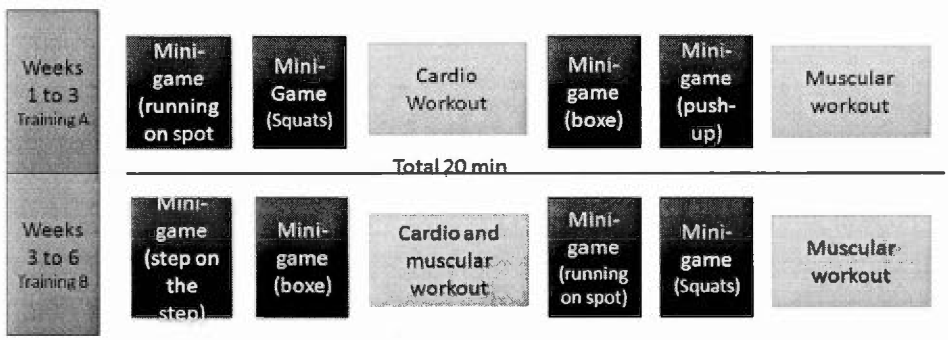

Figure 8. 1: Gameplay training

CHAPITRE IX: EXERGAMING ET MPOC

9.1. Mise en contexte

Les chapitres précédents présentaient une nouvelle mécanique de jeu vidéo actif où le joueur devait faire un nombre de répétitions maximales , où peu importe la condition physique de la personne, l'intensité se retrouvait près du maximum. Dans le cas de personnes atteintes de MPOC, les exercices peuvent être trop exigeants même s'ils tentent de faire qu'une seule répétition. De plus, selon les principes des jeux vidéo, afin que le joueur soit motivé à poursuivre, la difficulté ne doit pas être trop élevée. Toutefois, il est possible de modifier certains aspects du jeu vidéo actif afin de rendre accessibles les exercices demandés en plus de rencontrer les recommandations en activité physique chez cette population. Le présent chapitre propose une première étape vers un entraînement par les jeux vidéo actifs qui pourraient être effectués par la suite à la maison. Toutefois, une prochaine étude écologique demande à être poursuivie où l'utilisation d'un cardiofréquencemètre jumelée à un saturomètre pourrait être jumelée au jeu vidéo et permettre de générer des informations qui seraient envoyées à une équipe médicale de suivi à distance (télémédecine).

9.2. Résumé

La maladie pulmonaire obstructive chronique (MPOC) est une maladie respiratoire avec une détérioration significative de la qualité de vie, de la capacité fonctionnelle et une morbidité importante. Cependant, l'activité physique peut améliorer la condition physique, liée à une meilleure qualité de vie pour cette population. L'utilisation d'un

dispositif de capture de mouvement avec une session courte d'intensité élevée n'a jamais été essayée avec les patients atteints de MPOC. L'objectif était d'observer la faisabilité d'utiliser cet appareil facilement et en toute sécurité avec cette population. Un total de 14 patients (8 hommes 69 ± 6 ans, 6 femmes, 74 ± 6 ans), avec une forme modérée à sévère de MPOC diagnostiqué, ont effectué 4 mini-jeux (Shape-Up, Ubisoft) adaptés à leur condition. La session de jeu était d'une durée de 10 à 15 min et était composée de 4 jeux d'environ 1,5 min séparés par un repos. La ventilation moyenne et de pointe, et les METs de pointe étaient respectivement: Stunt Run (jeu où le patient doit lever les genoux sur place) 25,3 ± 6,8 L/min, 33,5 ± 8,2 L / min, et 4,2 ± 1,5 METs; Arctic Punch (jeux de boxe où il faut donner un coup de poing sur des cibles): 23,1 ± 5,6 L/min, 31,8 ± 9,8 L / min, et 3,7 ± 1,2 METs; To the Core (Torsion du tronc), 22,2 ± 7,3 L/min, 29,2 ± 9,9 L / min, et 3,3 ± 1,1, et Squat me to the moon (s'asseoir et se relever d'une chaise), 27,8 ± 6,7 L/min, 36,8 ± 11,1 L / min, et 4,4 ± 1,1 METs. Connaissant le plaisir rapporté par les participants, la sécurité et leur capacité d'utilisation assistés, il semble que le jeu peut être un bon outil pour le maintien de l'activité physique à la maison pour les patients atteints de MPOC. Cependant, une enquête plus approfondie est nécessaire afin d'observer les avantages de ce nouveau mode d'entraînement par rapport à un programme de formation traditionnel.

9.3. Article

9.3.1. Title: Pilot Project: Physiologic responses to a high-intensity active video game with COPD patients. Tools for home rehabilitation.

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9.3.2. Abstract

The Chronic Obstructive Pulmonary Disease (COPD) is a respiratory condition with a significant deterioration of the quality of life, physical function, and important morbidity. However, physical activity can improve fitness and is linked with a better quality of life for this population. Motion capture devices with short bursts of physical activity never been tried with COPD patients. Thus, the objective was to observe the feasibility of using this device safely and easily with this population. A total of 14 patients (8 men 69 ± 6 years, 6 women, 74 ± 6 years), with a moderate to severe COPD diagnostic performed 4 mini-games (Shape-Up, Ubisoft) adapted for their condition. Gaming sessions of 10 to 15 min duration were composed of 4 games of about 1.5 min separated with by rest. The average and peak minute ventilation, and the METs peak were respectively: Stunt Run game (lifting knees on the spot) 25.3±6.8L/min, 33.5±8.2 L/min, and 4.2±1.5 METs; Arctic Punch (punching targets): 23.1±5.6 L/min, 31.8±9.8 L/min, and 3.7±1.2 METs; To the Core (Core twist), 22.2±7.3L/min, 29.2±9.9 L/min, and 3.3±1.1 METs, and Squat me to the Moon (sitting to standing from a chair), 27.8±6.7L/min, 36.8±11.1 L/min, and 4.4±1.1 METs. Knowing the pleasure reported by the participants playing the games, the safety and, the ability to use it with assistance, it seems that the game can be a good tool for maintaining physical activity at home for COPD patients. However, further investigation needs to be completed in order to observe the benefits in comparison to a traditional training program.

Key words: Chronic obstructive pulmonary disease, exergaming, active video game, physical activity, energy expenditure, short High intensity training

9.3.3. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a highly prevalent condition and the fourth leading cause of mortality in Canada (Wardini et al. 2013). Pulmonary rehabilitation focuses on exercise and education intervention and has been shown to decrease symptoms of dyspnea, and improve exercise capacity and quality of life (Andrianopoulos et al. 2014). Despite these important benefits, maintaining a high level of physical activity after the rehabilitation remains a challenge for this population (Wardini et al. 2013). Furthermore, the pulmonary rehabilitation programs are difficult to access, in 2005 a mailed questionnaire estimated only 1.2% of the COPD population has accessibility to rehabilitation programs in Canada (Brook et al. 2007). It is for this reason that a tool for home exercise may help improve access and possibly the adherence to an active lifestyle (Ashworth et al. 2005; Polisena et al. 2010).

Active video games released recently have increased the type and range of physical activity at home and have been introduced into rehabilitation environments for different pathologies (Lohse et al. 2013). Parkinson's disease, sclerosis, post-stroke, and spinal cord injury patients have used active video games to supplement rehabilitation programs (Barry, Galna, and Rochester 2014; Bidiss and Irwin 2010; Kramer, Dettmers, and Gruber 2014). Two recent studies used an active video game with a motion controller (Wii) with patients with COPD, where LeGear et al. (2016) undergoing a home exercise program and Wardini et al (2013) proposed to add to the rehabilitation program. Both observed improvement in exercise capacity. However, the studies used a motion controller (Wii) and not a motion capture device (Kinect). Motion capture can provide biofeedback due to the capacity of the device to detect the skeleton of the patient, unlike the controller device where it only tracks the controller movement on one hand or on a foot pad (Sinclair, Hingston, and Masek 2007; Tanaka et al. 2012). Furthermore, other important skills can be improved with active video games for this population that have additional complications: such as balance deficiencies, cognitive decline, and limitations associated with an older population (Lohse et al. 2013; Taylor et al. 2012). Previous studies used a motion capture device (Kinect) to help balance recovery of a post-stroke patient and improving gait abilities, but also depression, and interpersonal relationships of stroke patients (Song and Park 2015).

Pulmonary rehabilitation programs are an integral part of the management of COPD. However the advantages depend on the training intensity (Gloeckl, Marinov, and Pitta 2013; Hsieh et al. 2007; Punzal, Kaplan, Prewitt 1991). Previous studies tried to observe if a continuous (constant load exercise) or an interval exercise induces more advantages for COPD patients However with the different workloads and protocol, the conclusions are inconsistent. Moreover, studies seem to observe fewer symptoms of dyspnea during the exercise, a better tolerance in perceived respiratory and peripheral muscle discomfort, and less frustration due to physical limitations (Gloeckl, Marinov, and Pitta 2013; Vogiatzis et al. 2004). Furthermore, it seems that for continuous and interval training, if the workload is at a high intensity, the benefits are important (Hsieh et al. 2007; Punzal, Kaplan, Prewitt 1991; Varga et al. 2007).

The primary aim of this study was to test the feasibility of using high intensity short duration active video games with a motion capture device (Kinect) with people with COPD before an eventual ecological study. We also measured the intensity and collected feedback from the participant in order to predict a possible effect and possible impact on this population in regards to previous studies. The final aim was to observe how the participants interacted with the games's environment.

9.3.4. Methods

9.3.5. Participants

14 patients with COPD (8 men, aged 69±6 years and 6 women, aged 74±6 years) were recruited at the Hotel-Dieu Hospital in Montréal, Qc. The participants were recruited through verbal invitation at the end of their rehabilitation session. Those with a cardiovascular disease, important musculoskeletal injury, epileptic history, or other physical activity restrictions were excluded from participation. Ethical approval for this study was obtained by the University of Quebec at Montreal's Faculty of Science Research Human Ethics Committee and a signed written consent form was obtained from all participants.

9.3.6. Procedures

Video Games Structure

The participants were active for a total of 30 minutes during one session only. The heart rate, the respiratory parameters (ventilation and breathing rate), and oxygen uptake were collected with a portative metabolic analyzer (MetaMax, Cortex, Germany). The numbers of repetitions of the exercises during the game (punch, core twist, and squat) were counted. The exhausted perception of the legs and the breathlessness perception were also taken on a Borg scale; a scale between 6 and 20, where 6 is under very, very light and 20 is just over very, very hard (O'Donnell et al. 1995).

The main instruction for the participants was to do as much they could during the time of the game (Shape-Up, Ubisoft Divertissement, Montréal) with a motion capture camera (Kinect). A count down at the top of the screen showed them the time left during the exercise. The game's instructions were given verbally with a short demonstration and were modified for the COPD population; including the following games: a running game (Stunt run), a boxing game (Arctic punch), a core twist game (To the core), and a squat game (Squat me to the Moon). The games's movements was modified to allow this population to complete the games as much as possible, and, to be engaged and motivated by the games. The participants were allowed to rest in a chair behind them at any time during the game. However, the timer in the game continued to run. The running game's (Stunt run) instructions were to raise their knees as high as they were comfortable doing as many times as they could during the time allowed. The game showed obstacles, however the participant was informed to disregard them if they considered it too difficult for the moment. The boxing game (Arctic punch) was programmed to follow the participant's pace, the instructions were to punch the highest number of targets that appeared randomly in 6 areas on the television screen. The instructions for the core twist game (To the core) were to put their hands on their hips and twist their core in order to navigate in the game. Finally, the squat game's (Squat me to the Moon) instructions were to sit on a chair and stand up as many times as they could. The participants performed the active games which took approximately 1.5 min each game. Between the games, the participant had a rest period on a chair in order to recover and where the mask from the metabolic analyzer was removed. The participants decided when they were ready to continue, which approximately 3-4 min, including the loading times of the games. Fig. 9.1 explains the different games and the exercise demands of these games

Data Analysis

The results are presented as mean ± standard deviation. An ANOVA repeated-measures was effectuated to observe significant difference in the intensity of the different games and if a difference between sexs was observed.

9.3.7. Results

Physiological responses

Fourteen participants with diagnosed COPD completed the session. Table 9.1 shows participants' descriptive data. The participants were in the moderate to severe category by the ATS/ERS Gold Standard (Celli et al. 2004) with a FEV1 % predicted to be 44 ± 14.8%, for the men it was 37.4±13.5% and for the women 52.8±12.3%, but without a significant difference between the sexs ($F(1)=3.307$, $p=0.096$). The predicted FEV1/VC % was < 70% (43.8 ± 15.2%), where for the men: 37.3±13.6% and for the women: 51.3±14.2% with a significant difference between the sexs ($F(1)=6.015$, $p=0.032$).

Table 10.3-2 presents the exercise data. The physiological parameters were the heart rate (HR), the oxygen uptake (VO_2), the METs, the minute ventilation (VE), tidal volume (Vt), the $FETCO_2$ at peak exercise, effort perception and breathlessness perception (Borg), and the number of repetitions and are presented with peak and average measurements during the 4 mini-games.

The differences between the games and the sexes are presented in table 9.3.

Difference between the sex

The heart rate peak and the Borg breathlessness did not show a significant difference between the sex (F(1.9)=0.202, p=0.664 and F(1.9)=3.26, p=0.105, respectively). However the VEpeak, VEaverage, and Vtaverage showed a significant difference between the sex: VEpeak; for Stunt Run and the Squat me to the Moon (p=0.001), and for Arctic Punch and To the core (p=0.002).. The VEaverage; for Stunt Run and Arctic Punch (p<0.001), To the core (p=0.001), and Squat me to the Moon (p=0.002), and for the Vtaverage; for Arctic punch (p=0.023), To the core (p=0.008) and Squat me to the Moon (p=0.05). Finally, the Vtpeak showed a significant difference between the sex (Stunt run p=0.027, Arctic punch p=0.002, To the core p=0.015, and Squat me to the Moon p=0.006), however not between games.

Difference between games

The heart rate peak and the Borg breathlessness did not show a significant difference between the games, as the sexs, as indicated above (F(1,9)=0.911, p=0.349 and F(1.9) 2.064, p=0.185, respectively). However the VE peak, VE average, and Vt average showed a significant difference for both. The differences between games for VE peak, VE average, and Vt average are: VE peak; between Stunt run and To the core (p=0.029), between Arctic punch and Squat me to the Moon (p=0.012), and between To the core and Squat me to the Moon (p=0.001), for VE average; between Stunt run and To the core (p=0.048), between Arctic punch and Squat me to the Moon (p=0.012), and between To the core and Squat me to the Moon (p=0.001), and for Vtaverage; Stunt run and To the core (p=0.029), To the core and Squat me to the Moon (p=0.002), and To the core and Squat me to the Moon (p=0.003). The other parameters showed a significant difference between games, but not between the sexs. The heart rate average had a significant difference between To the core and Squat me to the Moon ($p=0.007$), and the $V0_2$peak between Stunt run and To the core ($p=0.002$), Stunt run and Squat me to the Moon ($p<0.001$), and Arctic punch and Squat me to the Moon ($p=0.043$). The VO_2average had a significant difference between Stunt run and Arctic punch ($p=0.021$), Stunt run and To the core ($p=0.004$), Arctic punch and Squat me to the Moon ($p<0.001$), and To the core and Squat me to the Moon ($p<0.001$). The METs peak had a significant difference between Stunt run and To the core ($p=0.001$) and Arctic punch and Squat me to the Moon ($p=0.047$), and the METS average between Stunt run and To the core ($p=0.013$), Arctic punch and Squat me to the Moon ($p<0.001$), and Squat me to the Moon and To the core ($p<0.001$). Also, the FETCO2 showed a significant difference between Stunt run and To the core ($p=0.043$), and Borg leg between Stunt run and Arctic punch ($p=0.006$), Stunt run and To the core ($p=0.002$), Stunt run and Squat me to the Moon ($p=0.045$), Arctic punch and Squat me to the Moon ($p<0.001$), and To the core and Squat me to the Moon ($p<0.001$). Finally, the fig.10.3-2 show the VC/Vt demands of the different mini-game compared to rest.

Subjective comments

Breathlessness was the major reason to stop the exercise; however the games in general were reported to be between 9 and 17 on the Borg dyspnea scale (very light to very hard). The participants used 2 ways to reach the goals of the game, high intensity, but for a fraction of the time of the game or more slowly but completing the game. Some subjective comments were asked at the end of the session about the game perception by the participants and were written down. The participants seemed, in general, to like the game, but mostly they liked possibility to train at home, to have a possible tool to continue to do physical activity after their rehabilitation, where the duration is for only a few weeks. The comments were focused on the pleasure they experienced when they played, even if it is physically difficult, for example: "on se prend au jeu", "c'est le fun, mais ce n'est pas une partie de plaisir". The last one refers to the fun he had, but that it was physically demanding.

Another subjective part was observing the participants and how they interacted with the game and if they understood the task. We observed that the older participants had some difficulty in understanding the punching game, maybe due to the movement; cross punch. The other participants seemed comfortable during the game, the participants with more experience with technology were more comfortable. However, most of them shared that they will maybe not be comfortable to start and navigate in the game by themselves without clear reminders with pictures.

9.3.8. Discussion

The main finding of this study was that the participants with moderate to severe COPD succeeded to interact with the games and had an exercise response that showed an effort that reached exercise requirements for this population. The guidelines for exercise for patients with COPD recommend an intensity of 4-6 on 10-point Borg scale and an intensity of around 60-70% of the peak work rate for continuous exercise or 80-100% of the peak work rate for interval exercise (Gloeckl, Marinov, and Pitta 2013). These recommendations can be compared to the active video games, where the perceived exertion needed to be ''somewhat hard'' to ''hard'' (4-6 on 10-point Borg) and in this study the participants perceived, overall, from very light to very hard. The games corresponding to the perceived exertion of the guidelines were the Stunt Run and Squat me to the Moon games ("somewhat hard" to "hard"). Furthermore, in the following previous studies (Coppoolse et al. 1999; Hsieh et al. 2007) 80% of the peak work rate was related to a VO_2f around 12 ml/kg/min and a VE around 33-36 L/min. These values can be reached by the Stunt Run and Squat me to the Moon games. Furthermore, most of the participants were at the breathless tolerance, which was the reason why the participants that didn't complete the game time stopped, where we can possibly consider a maximal effort for these participants.

Intensity during previous studies with patients with COPD

Exercise training merits for patients with COPD are now well documented; an increase in exercise tolerance, a decrease in fatigue and breathlessness that improve quality of life, and a reduction of service care use (Gloeckl, Marinov, and Pitta 2013; O'Donnell and Gebke 2014). Despite these important benefits of exercise, few tools are on offer for this population when they return home after the rehabilitation program. Furthermore, the active video game tool used during the present study is a timely low-cost solution and relatively easy to use compared to present rehabilitation services. Moreover, high intensity training can be extremely beneficial compared to traditional modality exercises as shown in previous studies (Casaburi et al. 1991; Coppoolse et al. 1999; Maltais et al. 1996). High intensity interval training can improve exercise endurance, decrease the peak minute ventilation during submaximal exercise, decrease leg pain, and increase the peak work and the maximal inspiratory pressure (Casaburi et al. 1991; Coppoolse et al. 1999; Maltais et al. 1996) significantly more than continuous training. Even if this conclusion is disputed by other papers, it is accepted that for both continuous and interval training, if the intensity is high, the benefits are important (Hsieh et al. 2007; Varga et al. 2007). Previous efficient intensity training for an efficient rehabilitation training (Coppoolse et al. 1999), recruiting a similar population, age and spirometry parameters,, used an interval training at 90% of the peak work, which related to a VO_2 around 13 ml/kg/min. The Stunt Run and Squat me to the Moon games reached this value and the VE was considered maximal for this population, mostly because when the participants stopped the exercise before the end it was because of being breathless. Moreover, according to the O'Donnell and Laveneziana study (2006), the hyperinflation in severe COPD patients appeared around a VO_2 of 8 ml/kg/min, where, in the present study, the exercise induced by the games reached an intensity over this value, mainly for the Stunt Run and Squat me to the Moon games. Furthermore, the games were built for short training sessions, allowing the participants to be able to spend less time dedicated to an exercise and possibly improving the adherence (Stutts 2002). This new mode of training showed important benefits for inactive people, where for a low volume, high intensity training the participants increased their cardiorespiratory fitness and the glucose tolerance (Nybo et al. 2010). However, it does not seem to be documented with COPD. Furthermore, two important functional exercises are simulated, the best as possible with the technology available with active video game device; the sit-to-stand and walking test (Gloeckl, Marinov, and Pitta 2013) by the mini-games Squat me to the Moon and Stunt Run respectively. However, the walking test shows a pattern different than a real walking situation, where further investigation needs to be done between improvement during a walking test (6-min Walking test or the Incremental Shuttle Walking test) and the mini game Stunt Run. Nonetheless, the result of the sit-and stand test and 6-min walking test are strongly correlated with mortality in COPD (Pinto-Plata et al. 2004; Puhan et al. 2013). The present study showed a number of sit-and-stand during the game Squat me to the Moon, where the squat duration was 60 seconds, similar to the number of repetition for the sit-to-stand 60 seconds test (Puhan et al. 2013), showing a possible maximal intensity during the game. However, further investigation will be needed to look at the impact of the game in an ecological environment. Finally, the $FETCO_2$ and the ti/ttot triad reached the expected value for exercise with this population, whether around 4.5 % for the $FETC0_2$ (Van der Schans et al. 1994) and ti/ttot graph TRIAD, where the ttot was around 2 seconds at maximal exercise and a ti around 0.8 second (Díaz et al. 2002). Furthermore, the ratio between the vital capacity (VC) and the tidal volume (Vt) during the exercise was around 2, that was lower than Yan et al study (Yan, Kaminski, and Sliwinski 1997) where this ratio was around 2,7 with women with variable airflow obstruction at peak exercise. A lower ratio mean that the tidal volume during the exercise was closer to the vital capacity volume.

Intensity during previous studies using an active video game with patients with COPD

Previous studies using an active video game with COPD and rehabilitation patients seem to corroborate the feasibility and efficacy of an active video game with this population (LeGear et al. 2016; Wardini et al. 2013). However, these papers used a motion controller active video game (Wii), where the feedback is only linked to a hand controller or a foot pad. A movement capture device can allow for more biofeedback by analyzing the skeleton and giving recommendations on the movements (Tanaka et al. 2012; Taylor et al. 2012). Furthermore, the games selected by previous studies had an imposed pace, a determined intensity that cannot be modified. The previous studies didn't seem to take into consideration these important aspects in choosing the active video games and can have an important impact in the intensity and prescription of the active video game (Bidiss and Irwin 2010; Sell, Lillie, and Taylor 2010).The present study used a game where the pace is controlled by the participant, allowing a maximal intensity from the participant but also, a bigger possible range of intensity for the patient. However, like any active video game, the intensity and long-term adherence also depends on the participant's motivation (Biddiss and Irwin 2010; Peng and Crouse 2013; Sell, Lillie, and Taylor 2010). Finally, the exercise response was similar, and sometimes more demanding, during the present study than using the Wii training with this population. Wardini et al. (2013) monitored the heart rate at the end of the rehabilitation during the game, which was around 102 BPM, and the perception of dypnea (Borg) was at light. While in the present study the heart rate was between 93 and 110 BPM and the perception of dyspnea was ´´fairly light´´ to ´´somewhat hard/hard´´. Furthermore, the LeGear et al. (2016) study compared a Wii game with a treadmill exercise with patients with moderate COPD showed that the intensity observed was not significantly different and showed similar effort perception and dyspnea perception (Borg) as in the present study.

Furthermore, video games are also used in rehabilitation to help cognition and motor performance, where neuroplastic adaptations as a result of game play in some studies like spatial cognition can improve attention capacity, reaction time, and working memory capacity (Lohse et al. 2013). In the present study the Arctic punch and To the core games seem to be cognitively demanding for some of the participants, possibly due to the chosen reaction time when they needed to punch the target (Arctic punch) or avoid the target (To the core) and the visuospatial reasoning. These games did not reach the intensity requirements indicated the ATS guidelines, but maybe can help manage other complications of COPD like cognitive impairment (memory and attention) through coordination and reaction time demands elicited by the game (López-Torres et al. 2015). However, further study is needed to be done to know the possible benefits.

Recommendations

Further investigations will need to be done to see the feasibility of using games at home for this population, mostly due to the utilization of the technology. Some participants had no problem in interacting with the technology, while some others were afraid to break something. It is important to consider this before proposing this activity in order to maintain physical activity with this population. A saturation monitor with an alarm can be a good way to prevent, and ensure the safety from, possible oxygen desaturation knowing that the set-point for the game/exercise is a maximal completion. Even if no problem has happened during this project or previous active video game study; the safety and well-being of the participants are a main consideration and can be improved by this low cost and non-invasive solution. Monitoring the heart rate, saturation and ventilation during the sessions and being able to send it in an easy way can be useful in following the patient and giving precious information to the clinical team. The game also allows the creation of a community and the ability to send performances, so it can be interesting to see if this option can have an impact on the social problems with COPD patients, where most of them are isolated (Lohse et al. 2013). The major problem with all these recommendations is the potential lack of comfort with technology, maybe considering and identifying their familiarity with technology before proposing this kind of solution. It is important to note that this technology can probably help the patient to stay active, but cannot replace a pulmonary rehabilitation program where important techniques and daily life tips are taught.

9.3.9. Conclusion

The current pilot-project suggests that a gaming-based exercise program was enjoyable and provides feasible high intensity exercise as a possibility for use after rehabilitation. Furthermore, the Stunt Run and Squat me to the Moon games reach exercise intensity guidelines for COPD patients. However, further investigation on the ecological application, and the long-term benefits and adherence are required.

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9.3.11. Tables

Table 9. 1: Participants characteristics

	Overall	**By sex**	
Characteristics	(n=14)	Men (n=8)	Women(n=6)
Age (years)	71 ± 7	69 ± 6	74 ± 6
Height (cm)	164.0± 7.9	168.6± 6.5	157.8.0 ± 5.0 *
Weight (kg)	69.1 ± 13.9	76.4 ± 10.7	59.5 ± 12.2 *

Vital capacity (L)	2.47 ±0.75	2.80±0.75	2.02 ±0.49*
FEV1 (L)	1.12 ± 0.38	1.18 ± 0.47	1.03 ± 0.24
%FEV1 predicted	44.0 ± 14.8	37.4 ± 13.5	52.8 ± 12.3
	(severe, stage III), ATS/ERS GOLD criteria	(severe, stage III), ATS/ERS GOLD criteria	(moderate, stage II), ATS/ERS GOLD criteria
FEV1/VC (%)	43.8 ± 15.2	37.3 ± 13.6	51.3 ± 14.2*

Mean±Standard Deviation

Table 9. 2:Cardiorespiratory and perception parameters during the different mini-games

Parameters	Stunt Run	Arctic Punch	To the Core	Squat me to the Moon'
Heart rate peak (BPM)	106 ± 14	104 ± 20	98 ± 17	110 ± 13
Heart rate average (bpm)	98 ± 14	95 ± 14	93 ± 15	102 ± 13
VO_2 peak (ml/kg/min)	14.4 ± 3.8	12.3 ± 4.2	11.1 ± 3.7	14.8 ± 3.9
VO_2 average (ml/kg/min)	9.8 ± 2.3	7.9 ± 1.8	7.3 ± 2.5	10.6 ± 2.6
METS peak	4.20 ± 1.50	3.69±1.18	3.26±1.07	4.44±1.06
METS average	3.00 ± 3.82	2.37 ± 0.54	2.24±0.68	3.16±0.72
Ve peak (L/min)	33.5 ± 8.2	31.7 ± 9.8	29.2 ± 9.9	36.8 ± 11.1
Ve average (L/min)	25.3 ± 6.8	23.1 ± 5.6	22.2 ± 7.3	27.8 ± 6.7

Vt average (L)	0.97 ± 0.22	0.81 ±0.18	0.87 ± 0.19	1.03±0.30
Vt peak (L)	1.39 ± 0.22	1.41 ± 0.29	1.25 ± 0.33	1.38 ± 0.39
$FetCO_2$ at effort peak (%)	4.74 ± 0.23	4.36±0.63	4.07±0.74	4.75±0.67
% of the game completed	67±14	77±31	87±19	71±6
Borg leg	13 ± 1	10 ± 1	10 ± 2	14 ± 2
Borg breathless[‡]	12 ± 3	11 ± 2	11 ± 2	14 ± 3
Nb repetitions	N/A	26 ± 24	46 ±14	20 ± 6

Mean±Standard Deviation; [†]: n=13, one of the participants had knee surgery in the past; [‡]:n=11, technical problem

Table 9.3: Different mini-games and sex compared p values

Parameters	**Stunt Run**	**Arctic Punch**	**To the Core**	**Squat me to the Moon'**
Stunt Run	X	VO_2average ($p=0.021$)	VO_2peak ($p=0.002$)	VO_2peak ($p<0.001$)
		Borg leg ($p=0.006$)	VO_2average ($p=0.004$)	Borg leg ($p=0.015$)
			Ve peak ($p=0.029$)	
			VEaverage ($p=0.004$)	
			METs ($p=0.001$)	
			METs average ($p=0.013$)	

			$FetCO_2$ (p=0.043)	
			Borg leg (p=0.002)	
Arctic Punch	See line 1	X	X	VO_2peak (p=0.043)
				VO_2average (p<0.001)
				Ve peak (p=0.012)
				Ve average (p<0.001)
				Vt average (p=0.002)
				METs peak (p=0.047)
				METs average (p<0.001)
				Borg leg (p<0.001)

To the Core	See line 1	X	X	HRaverage ($p=0.007$) VO_2average ($p<0.001$) Ve peak ($p=0.001$) Ve average ($p=0.001$) Vt average ($p=0.003$) METs peak ($p<0.001$) METs average ($p<0.001$) Borg leg ($p<0.001$)
Squat me to the moon	See line 1	See line 2	See line 3	X
Sex differences				

Ve peak	p=0.001	p=0.002	p=0.002	p=0.001
Ve average	p<0.001	p<0.001	p=0.001	p=0.002
Vt preak	p=0.027	p=0.002	p=0.015	p=0.006
Vt average	X	p=0.023	0.008	P=0.05

9.3.12. Figures

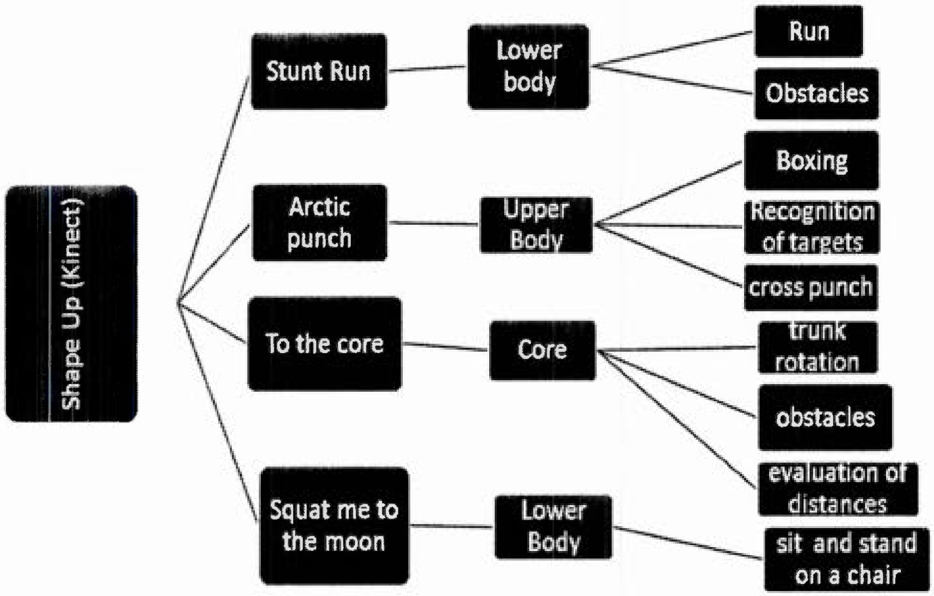

Figure 9. 1:Description of the mini-games Participants were asked to do the 4 mini-games.

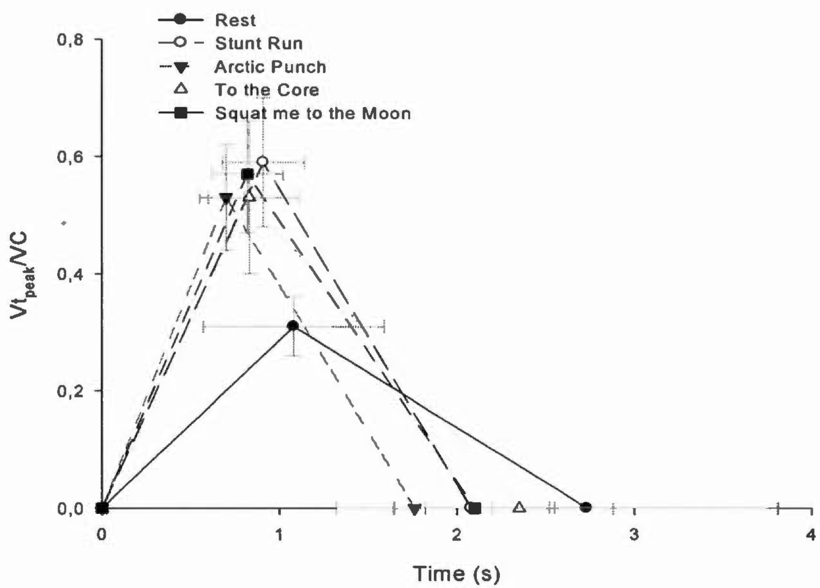

Figure 9.2:Relationship between the tidal volume (Vt), corrected by the vital capacity (VC) at peak intensity during the game and the inspiratory time and total respiratory time TRIAD

CHAPITRE X: DISCUSSION

10.1. Discussion générale

Le but de la thèse était d'observer des réponses physiologiques afin de mieux comprendre les mécanismes en lien avec les contraintes augmentées et ainsi proposer et tester des solutions innovatrices afin d'assurer la performance et la sécurité des personnes en situation de contraintes augmentées. Les situations de contraintes augmentées étaient une expédition en Antarctique et un entraînement par des jeux vidéo actifs pour des personnes atteintes de MPOC.

La principale observation de cette thèse est que l'utilisation des technologies de télémédecines a été favorable à l'observation de réponses physiologiques dans les milieux de contraintes augmentées, par contre certaines améliorations pourraient être effectuées. Les principales observations ont été le maintien, voire l'amélioration de la masse maigre chez les explorateurs ainsi que le maintien des capacités physiques, alors qu'une dégradation est généralement observée à la suite d'expédition polaire (Frykman et coll. 2003; Halsey et Stroud 2012). Il en est de même pour les améliorations de la condition physique par l'utilisation des jeux vidéo actifs, plusieurs études dans le passé considéraient que ce type d'exercice ne permettait pas une intensité assez élevée pour induire une amélioration de la condition physique (Bidiss et Irwin 2010), alors qu'avec les présents travaux il a été possible d'observer une plus grande amélioration de la condition physique à l'aide d'un jeu vidéo actif que lors d'un entraînement traditionnel, ainsi que l'observation de réponses physiologiques prometteuse pour un entraînement en réadaptation pulmonaire chez des patients atteints de MPOC.

10.1.1. Réponses physiologiques en Antarctique.

Bien que la télémédecine ait permis de suivre plusieurs réponses physiologiques durant l'expédition, certaines mesures ont dû être effectuées avant et après l'expédition due aux restrictions de l'expédition et des appareils. Ces mesures ont permis d'observer l'impact de l'expédition sur: l'anthropométrie, la force et l'endurance musculaire, les capacités cardiorespiratoires ainsi que les réponses physiologiques à l'exercice en environnement froid. Il a d'ailleurs été possible d'observer les réponses physiologiques chez des femmes alors que les études en expédition polaire en complète autonomie sont effectuées sur des hommes.

Anthropométrie et condition physique

La masse maigre maintenue, voire augmentée chez les femmes a possiblement contribuer à conserver l'endurance et la force musculaire, sans oublier une amélioration significative au niveau de la force de la jambe gauche chez les participantes, toutes droitières. Cette amélioration est probablement due à la jambe de propulsion de départ lors de l'expédition qui comprend plusieurs arrêts et départ en tirant un traîneau où la friction par la neige n'est pas négligeable. Cette amélioration fut plus que surprenante, sachant que plusieurs expéditions polaires précédentes observent une diminution de la masse maigre (Halsey et Stroud 2012; Stroud, Jackson, et Waterlow 1996), majoritairement causée par un déficit énergétique menant à une perte critique du % de gras et une diminution de la masse musculaire provenant de la masse maigre possiblement contribuant à fournir l'énergie nécessaire à la survie des explorateurs (Brotherhood et coll. 1986; Frykman et coll. 2003; Stroud 2001; Stroud, Jackson, et Waterlow 1996). Cette balance énergétique négative est majoritairement due à la demande énergétique accrue par les conditions polaires et à la demande de l'activité de transporter un poids important de matériel et de nourriture à l'aide de sac à dos et de traîneaux, alors que la diète est généralement souvent insuffisante en calorie, majoritairement au niveau des lipides et des glucides afin de lutter contre cette demande énergétique (Frykman et coll. 2003; Halsey et coll. 2016; Halsey et Stroud 2012; Stroud 1998). Ce débalancement énergétique mène généralement à une dégradation des capacités physiologiques essentielles à la continuation de l'expédition et peu mener à des conséquences importantes (Halsey et Stroud 2012).

Les résultats de la présente étude, en plus d'éviter une perte de force et d'endurance musculaires, a permis de démontrer chez les membres de l'expédition une amélioration significative de consommation maximale d'oxygène au test cardiovasculaire spécifique (SMAT), possiblement causé par le maintien de la masse maigre et voir même amélioré chez les femmes, où la masse musculaire joue un rôle sur la quantité d'oxygène pouvant être consommée, corroborant les observations de Frykman et coll. (2003) ainsi que Helge et coll. (2003). Ces auteurs ont observé également une préférence pour les fibres de type 1 (lente) durant l'expédition où la capacité cardiorespiratoire pouvait être augmentée après l'expédition au détriment des fibres de type 2 (rapide), où une diminution de la capacité anaérobique était observée.

Acclimatation au froid

Les composantes de la condition physique évaluée à la température tempérée ne permettaient pas d'observer les acclimatations physiologiques au froid. C'est pourquoi, une comparaison entre des tests physiologiques effectués en température tempérée vs les mêmes tests effectués en température froide a permis d'observer comment les réponses physiologiques après une exposition prolongée à un environnement froid. Il a été observé que la consommation d'oxygène (VO_2) à exercice sous-maximal était significativement plus basse au froid après l'expédition sans être expliqué par une amélioration de la VO_2 à la température tempérée. Il semble qu'une économie du coût métabolique s'est effectuée après l'exposition prolongée au froid. Toutefois, nos mesures ne permettant pas d'expliquer les mécanismes sous-jacents seul des hypothèses provenant d'articles précédents peuvent être émises. Oska et coll (2004) tentent d'expliquer ce phénomène par 3 hypothèses lors d'une exposition ponctuelle. Toutefois, comme les articles précédents sur les réponses cardiorespiratoires à l'exercice sous-maximal n'étudient pas l'acclimatation après exposition au froid de longue durée ces 3 hypothèses sont le point de départ pour l'instant afin d'expliquer ce phénomène:1) une possible circulation sanguine réduite par l'exposition au froid, 2) des changements neuromusculaires seraient plus lents en exposition au froid et 3) une constriction respiratoire du à l'exposition à un environnement froid mènerait une diminution de l'oxygène pouvant être utilisé . Par contre, des études plus approndondies devront être effectuées pour confirmer ou non ces hypothèses.

Mesures en télémédecine durant l'expédition

Les mesures effectuées et recueillies avec le vêtement intelligent durant l'expédition pouvaient être transmises via internet afin de suivre l'équipe. Ce type de télémédecine peut s'avérer très utile afin de diminuer les risques de blessures, d'hypothermie et d'épuisement où les explorateurs d'expédition polaire sont souvent exposés. Peu d'articles présentent une méthodologie de télémédecine en prévention et pourtant des analyses ergonomiques montrent plusieurs normes pour des travaux ayant plusieurs similitudes et où les risques peuvent être important si un suivi de la charge de travail n'est pas effectué (Çalişkan et Çağlar 2010). Parmi ces mesures la température orale, le temps de réaction, les fréquences cardiaques et les fréquences respiratoires peuvent permettre d'avoir une première idée des risques reliés à la fatigue (surcharge) et à la qualité de sommeil (Raymann, Swaab, et Van Someren 2007) des explorateurs. Ces mesures sont déterminantes dans les risques de blessures, mais également dans les mécanismes de thermorégulation et de tolérance au froid (Young et coll. 1998). Dans la présente étude, la température orale prise au réveil le matin ainsi que la température cutanée durant la nuit a permis d'observer que les membres de l'expédition étaient en mesure de se protéger du froid adéquatement à l'aide des vêtements et de l'équipement le plus récent sur le marché. Cette capacité à garder la chaleur est un élément important pour la qualité du sommeil et la diminution des risques d'hypothermie, mais aussi pour éviter les risques au niveau du système respiratoire. Une exposition au froid prolongé lors d'exercice de haute intensité pourrait avoir des conséquences néfastes de bronchoconstriction (Rundell and Jenkinson 2002; Wilber and Rundell 2000). Ce qui n'a pas été observé via les tests de spirométrie à la suite de l'expédition.

Un dernier aspect qui a pu être mesuré durant l'expédition est le temps de réaction simple et au choix, la perception de l'effort et le questionnaire d'émotions. Ces mesures peuvent renseigner l'équipe médicale sur les risques de dépression et d'anxiété (Crawford and Henry 2004) ainsi que le temps de réaction qui pourraient faire une différence importante dans la survie de l'équipe lors de situation de survie tel que les chutes de crevasses et durant les avalanches. Le milieu polaire peut imposer un niveau d'anxiété et de stress important (Bishop, Grobler, and Schjoii 2001), c'est pourquoi le cortisol salivaire et des cheveux (Stalder and Kirschbaum 2012) ont été analysés après l'expédition. Aucune différence significative n'a été observée durant les différentes étapes de l'expédition, par contre la réponse générale, durant le mois entier a augmenté significativement le cortisol capillaire en comparaison avec le mois de préparation. Ce stress important indique l'importance de suivre l'équipe dans son ensemble autant physiologiquement que psychologiquement due aux multiples facteurs de stress environnementaux et de la demande de l'expédition avant, pendant et après une expédition de ce type.

Études futures

Il est à noter que l'expédition en complète autonomie comprenait des femmes. L'étude de la différenciation des sexes dans ce type d'expédition n'a jamais été étudiée à notre connaissance. Malheureusement, les données n'ont été effectuées que chez trois femmes vs trois hommes (2 pour les données anthropométriques étant donné que l'un d'eux est tombé malade). Des études plus approfondies devront être effectuées, mais les données recueillies permettent une première piste vers ce type de recherche où les changements anthropométriques semblent évoluer de manière différente significative selon le sexe.

10.1.2. Risques physiologiques désavantageux reliés à l'inactivité et utilisation de jeux vidéo pour le milieu clinique/réadaptation.

Avant d'utiliser une nouvelle technologie, dans notre cas l'utilisation de jeux vidéo actifs jumelée à un cardiofréquencemètre pour l'entraînement, il a été important de le tester sur une population comportant moins de limitations et risques lors de l'exécution d'exercice physique que les patients participants à des programmes de réadaptation.

Une population inactive, mais sans restriction à l'activité physique était la population idéale afin de tester cette technologie. L'inactivité est reliée à une augmentation du risque de maladies cardiovasculaires, diminution de la condition physique, pouvant mener jusqu'à une perte importante de la capacité fonctionnelle lors du vieillissement (Garber et coll. 2011). Afin de réduire ces risques, l'ACSM a émis des recommandations, dont la pratique d'activité physique quotidienne. Ces recommandations indiquent qu'un adulte devrait pratiquer minimalement 150 min d'activité physique modérée à vigoureux ou un total de 500kcal/semaine (Garber et coll. 2011) afin de diminuer les risques pour la santé. Toutefois, d'autres études récentes mentionnent qu'il serait possible de profiter des effets bénéfiques de l'activité physique sur la santé avec un volume réduit par un entraînement en intervalle de haute intensité (HIIT)(Gillen and Gibala 2014; Wisløff, Ellingsen, and Kemi 2009). En plus d'observer une amélioration en moins de temps et de calories totales dépensées par semaine, les améliorations pouvaient être observées avec aussi peu que 2 semaines d'entraînement (Burgomaster et coll. 2005; Gibala 2007; Gillen and Gibala 2014). Il est également possible d'observer une meilleure rétention à un mode vie actif, où le temps est une des barrières les plus importantes chez les personnes inactives (Stutts 2002).

Dans la présente thèse, il a été possible d'observer des réponses physiologiques corroborant ces observations mentionnées ci-haut avec un entraînement à l'aide d'un jeu vidéo actif (Shape-Up, Ubisoft, Montréal). Le jeu a permis une amélioration significative d'un nombre plus élevé des mesures reliées à la condition physique que l'entraînement traditionnel, avec seulement 60 à 80 minutes d'activité physique ludique à comparer à un minimum de 150 minutes d'activité physique structuré dans une salle de conditionnement physique. La structure du jeu permettait un entraînement en HIIT, ce qui était surprenant sachant que la majorité des jeux vidéo actifs ne sont pas recommandés par l'ACSM et que des études antérieures considéraient ce type de jeu incompatible avec les recommandations en activité physique dues à une intensité trop faible des activités (Biddiss and Irwin 2010; Donovan and Hussey 2012). La mécanique de jeu du jeu vidéo actif utilisée dans cette thèse est innovatrice et permet une intensité élevée. Toutefois, il est à noter que d'autres jeux vidéo actifs où les mécanismes de jeux et le type de détection de mouvements n'étaient pas pris en considération par les auteurs peuvent atteindre des intensités d'exercice également élevées. Il a été possible d'observer que pour les jeux utilisant uniquement une manette pour détecter le mouvement, le joueur dépensait moins d'énergie pour une même activité/jeu. O'Donnovan (2012) corroborait cette observation, possiblement due à l'alternative d'utiliser une technique économique pour diriger la manette afin d'atteindre le but du jeu, alors qu'un jeu vidéo actif utilisant un analyseur de mouvement détectera la "tricherie" du joueur. Il avait d'ailleurs été possible d'observer des intensités de jeux vidéo actifs entre modérée et vigoureux pour les jeux de danse, d'entraînement et le jeu d'action par détection de mouvement (Kinect). Toutefois, il est à noter que le jeu Shape Up permettait d'observer une plus grande intensité d'activité physique par sa mécanique de jeu innovatrice, où le joueur se doit de faire un maximum de répétition d'un mouvement simple au lieu de devoir suivre une cadence imposée par le jeu.

10.1.3. Utilisation de jeux vidéo actifs en réadaptation de personnes atteintes de MPOC: possibilité d'une solution par télémédecine

Les jeux vidéo actifs d'intervalles à haute intensité pourraient permettre un entraînement à la maison pour les patients atteints de MPOC. Les réponses physiologiques mesurées lors du test de jeu vidéo actif Shape-Up a permis de rencontrer les recommandations de l'ATS en plus de rencontrer les recommandations d'autres articles en incluant un entraînement d'endurance cardiorespiratoire jumelée à un entraînement musculaire fonctionnel (Casanova et coll. 2008; Gloeckl, Marinov, and Pitta 2013; Puhan et coll. 2013). Ce type d'entraînement permettrait d'améliorer les capacités fonctionnelles et donc possiblement améliorer la qualité de vie (Monsó et coll. 1998). Une telle solution permettrait également un accès plus rapide pour certains patients à un mode de réadaptation et idéalement une solution pour aider ces patients à demeurer actifs. Ce dernier point est important sachant que plusieurs patients arrêtent la pratique de l'activité physique après un programme de réadaptation pulmonaire en institution ce qui mène à un déconditionnement et un retour au cercle vicieux diminuant la qualité de vie (Monsó et coll. 1998; O'Donnell et coll. 2012; Yohannes et coll. 1998). L'ATS recommande un entraînement ayant une intensité située entre 4à 6 sur une échelle de Borg modifié sur 10. Cette intensité équivaut environ à 12 ml/kg/min de VO_2 et une ventilation d'environ 33-36 L/min (Coppoolse et coll. 1999; Hsieh et coll. 2007), ce qui équivaut aux observations dans la présente thèse et où parfois une intensité plus élevée a été notée durant les mini-jeux dans Shape-Up de Squat me to the Moon et Stunt Run. Ceci corrobore l'étude de (Bjørgen et coll. 2009; Gloeckl, Marinov, and Pitta 2013; Punzal, Kaplan , Prewitt 1991) précisant qu'un entraînement de HIIT semblerait bénéfique pour les patients MPOC modérée à sévère, car la sensation de dyspnée est réduite et permettrait une plus grande amélioration de la condition physique. De plus, ces deux jeux équivaut à de la marche et un relevée de chaises, deux exercices corrélés à la qualité de vie et à un risque moins élevé de mortalité (Casanova et coll. 2008; Puhan et coll. 2013).

Dans le cercle de qualité de vie, la perte de faculté cognitive peut être un problème pour certains patients qui ont déjà un âge avancé. Le mini-jeu Arctic Punch dans ShapeUp se veut une petite récupération active, mais également permet de travailler des fonctions cognitives. D'ailleurs, il a été reporté par Lohse et coll. en 2013 que l'utilisation de jeu vidéo pouvait permettre d'observer une amélioration de la mémoire, du raisonnement visuospatial, le temps de réaction la capacité d'attention et la précision de réponses dans un test de temps de réaction à choix de réponse. Toutefois, des études plus approfondies devront être effectuées pour observer si ce jeu pourrait vraiment avoir un impact positif sur les fonctions cognitives pour ces patients, ou en général chez une population âgée. De plus, l'aspect social du jeu où il est possible d'envoyer ses performances à d'autres patients en plus de l'équipe médicale pourrait motiver le patient à s'entraîner avec ce jeu, améliorant l'adhésion et également jouer un rôle dans la qualité de vie. Néanmoins, ces hypothèses demanderaient à être confirmées dans une future étude.

10.2. Limitations

10.2.1. Exploration en Antarctique

La présente thèse comporte certaines limites dont l'échantillon restreint d'explorateurs en Antarctique. Il est à noter que malgré le nombre restreint pour la puissance statistique, il est rare de mesurer durant une expédition autant de personnes. Il est majoritairement observé dans les études antérieures un nombre de participants qui se situe à un ou deux explorateurs et habituellement uniquement sur des hommes. Une autre de ces limites est que certaines mesures ne sont pas disponibles en appareil portable et/ou milieu standardisé et devaient être effectuées avant et après l'expédition sur le continent Antarctique. Des appareils portatifs plus précis, accessibles et résistants aux contraintes de l'expédition permettraient de prendre davantage de mesures sur le terrain. Il est également à souligner que les mesures ont été prises sur le terrain, permettant une validité écologique, mais ne nous permettant pas de standardiser les conditions environnementales. Donc, il est difficile de généraliser aux autres expéditions en complète autonomie en Antarctique.

10.2.2. Jeux vidéo actifs

Plusieurs limites similaires recoupent les projets avec les jeux vidéo. Les jeux vidéo actifs utilisés ne peuvent être généralisés à tous les autres jeux vidéo actifs et c'est pourquoi le type de console et les mécaniques de jeux doivent être analysés avant de faire un choix éclairé, que ce soit à des fins de promotion de l'activité physique ou de réadaptation. De plus, les données présentées actuellement n'ont pu être effectuées qu'en validation clinique pour une seule séance, mais des études plus poussées devront être performées afin d'observer les changements physiologiques à la maison sur une plus longue période de temps. De plus, cette prochaine étude devra comprendre l'observation de ce type de jeu sur la rétention, les capacités fonctionnelles et les fonctions cognitives afin d'observer lors d'une validation écologique, les impacts d'un entraînement à l'aide du jeu vidéo actif à intervalle de haute intensité à la maison. Finalement, l'efficacité des données envoyées par télémédecine à l'équipe médicale devra être validée afin d'apporter les modifications nécessaires avant l'implantation d'une telle technologie dans le système de la santé. Il est également à noter que les patients MPOC sont souvent âgés et possiblement parfois anxieux lors de l'utilisation de nouveaux appareils technologiques, il est donc possible que pour certains d'entre eux cette méthode d'entraînement à la maison ne conviendrait pas.

10.3. Recommandations générales

L'évolution des technologies actuelles est prometteuse afin d'aider la télémédecine (Bashshur, Reardon, et Shannon 2000; Craig and Patterson 2005; Maglaveras et coll. 2005; Wootton 1997)permettant un plus grand nombre de personnes d'avoir accès à des soins ainsi que de déployer plus facilement la tâche des professionnels de la santé dans l'analyse des mesures physiologiques. La qualité du signal pour un format portable, l'analyse et l'exportation à la l'équipe médical ainsi que les coûts peuvent être des barrières importantes (Bashshur, Reardon, and Shannon 2000; Polisena et coll. 2010; Wootton 1997).Néanmoins, il a été possible d'observer que ce type de technologie n'est pas impossible. Que ce soit dans le but de permettre une solution ludique et simple d'entraînement en réadaptation de patients MPOC ou bien de suivre certaines données physiologiques pour diminuer les risques lors d'expédition, les nouvelles technologies permettent aisément de transférer les informations via internet à l'équipe médicale. Bien que certaines mesures soient plus difficilement accessibles en format portatif, certaines solutions de suivis ont pu être proposées à travers cette thèse et ne pourront qu'être bonifiées avec l'évolution rapide des technologies de télémédecine.

CHAPITRE XI: CONCLUSION

La présente thèse se penchait sur le potentiel des technologies en télémédecine où il semble y avoir plusieurs applications pour l'avenir. Le but était d'observer les réponses physiologiques lors de contraintes augmentées, soit une expédition en Antarctique et la validation clinique d'un entraînement à l'aide de jeux vidéo actifs de haute intensité avec des patients MPOC. De plus, un sous-objectif était de proposer, à l'aide de la télémédecine actuelle, des pistes de solutions à ces contraintes. La démarche principale était de mesurer les réponses physiologiques de ces contraintes avant, pendant et après à l'aide d'évaluations de la condition physique et d'appareils de télémédecine. Il semble apparent à la lumière des diverses études présentées au travers de la thèse que ces nouvelles technologies offrent des pistes de solution à exploité pour le suivi à distance de signes vitaux (Antarctique et Astroskin), l'entraînement (jeux vidéo et cardiofréquencemètre) et de la réadaptation (jeux vidéo, cardiofréquencemètre jumelé à un saturomètre et MPOC).

Les résultats les plus saillants ont été, pour l'expédition en Antarctique le maintien chez les hommes et l'augmentation chez les femmes de la masse maigre après une expédition en complète autonomie en Antarctique, ainsi que le maintien de la condition physique des explorateurs à la suite de cette contrainte. Pour ce qui est des observations avec les jeux vidéo actifs, les résultats majeurs ont été que certaines mécaniques de jeux pouvaient permettre aux joueurs d'atteindre une intensité élevée. Pour le jeu vidéo actif de haute intensité d'activité physique, les réponses physiologiques durant le mini-jeu de lever de chaise et de marche correspondaient aux recommandations de l'ATS pour les patients MPOC modérée à sévère. Il a d'ailleurs été observé que ces mêmes jeux correspondant également aux normes de l'ACSM pour des personnes inactivent. Toutefois, il est à noter que certaines limites ne permettent pas de généraliser les observations. D'ailleurs, le nombre d'explorateurs était limité et la technologie accessible limitait les mesures prises durant l'expédition. De plus, les tests effectués chez les patients MPOC étaient une première étude de faisabilité en centre clinique où une étude de faisabilité écologique devra être effectuée afin d'observer l'impact de ce jeu sur l'attrition, les capacités cognitives ainsi que sur la capacité fonctionnelle après quelques semaines d'entraînement à l'aide de ce jeu aux domiciles des patients. Pour conclure, la télémédecine a beaucoup de potentiel afin de diminuer les risques et offrir de nouvelles solutions face à des contraintes augmentées. Toutefois, cette technologie se doit de continuer à évoluer afin de permettre plus de possibilités.

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