UNIVERSITAT DE BARCELONA

Personalització de les recomanacions d'exercici per a la salut. Perspectiva de la Fisiologia de Xarxes

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A les persones que surfejen les onades, entre la salut i la malaltia.

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"In the symphony of life every rhythm, every beat, every pulse, and every connection orchestrates the dance"

N.B. & R.H.

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MariCarmen

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Resum

Introducció: La inactivitat física i el sedentarisme són preocupacions significatives per a la salut en la societat contemporània. Amb l'objectiu de millorar els resultats de salut i reduir els riscos associats, l'Organització Mundial de la Salut (OMS) ha establert unes directrius universals d'activitat física adreçades a diferents segments de la població. Amb el suport tant d'institucions públiques com privades, les directrius de l'OMS són una referència per a la prescripció d'exercici en diverses regions i països. No obstant això, els seus supòsits teòrics i evidencies científiques són qüestionables des de la perspectiva de la Fisiologia de Xarxes de l'Exercici *("Network Physiology of Exercise" - NPE*), una nova branca de coneixement emergida de l'aplicació de les Ciències de la Complexitat i la Ciència de Xarxes a la Fisiologia. La concepció de l'organisme com una xarxa complexa amb propietats ignorades fins el moment ofereix la possibilitat d'actualitzar les directrius de l'OMS, contribuint així a la millora de la salut de la població. En base a una re-definició del fitness i a una concepció persona-entorn derivada de l'aplicació de principis de la NPE, es proposa en el teletreball una participació activa dels usuaris/àries en les intervencions d'exercici capaç de desenvolupar la seva consciència interoceptiva.

Objectiu: L'objectiu d'aquesta tesi és revisar i actualitzar les directrius d'exercici per a la salut de l'OMS en base a la perspectiva de la NPE i oferir uns criteris generals per a l'elaboració de recomanacions d'exercici personalitzades que puguin garantir una major adherència de la població a l'activitat física. En específic, contrastar els efectes sobre la condició física, la salut mental i la consciència interoceptiva d'una intervenció d'exercici co-dissenyada, basada en els principis de la NPE, amb un programa d'exercici basat en les recomanacions de l'OMS per a adults sans.

Mètode: Vint adults sans (10 homes i 10 dones, de 40 a 55 anys) van participar voluntàriament en la recerca. Es van assignar aleatòriament a una intervenció d'exercici co-dissenyada (grup CoD) i a un programa d'exercici basat en les recomanacions de l'OMS (grup OMS). Supervisats en línia per entrenadors personals especialitzats, els dos programes, equivalents en volum i intensitat, es van aplicar durant 9 setmanes. Els efectes de la intervenció d'exercici es van mesurar a través d'entrevistes personals, que van valorar l'autonomia i auto-regulació de l'exercici, qüestionaris de salut mental (DASS-21) i consciència interoceptiva (MAIA) i una prova d'esforç càrdio-respiratòria. Les diferències intra-grup (pre-post) es van avaluar utilitzant la prova de Mann-Whitney Wilcoxon i les diferències inter-grup mitjançant proves t de Student. Les mides de l'efecte es van calcular mitjançant la d de Cohen. Les entrevistes es van valorar mitjançant anàlisi de contingut.

Resultats: La re-conceptualització de la salut i el fitness com a estats multidimensionals, dinàmics, subjectius i dependents del context permet desenvolupar uns criteris d'exercici que pretenen desenvolupar l'auto-responsabilitat, l'auto-gestió i l'adherència a l'exercici de la població. El programa d'exercici arrelat en els principis de la NPE, va mostrar més efectivitat pel desenvolupament de la salut mental, la consciència interoceptiva, l'autonomia i l'autoregulació de l'exercici en comparació amb el programa basat en les directrius de l'OMS. Ambdós grups van millorar, no significativament, els resultats de les proves càrdio-respiratòries, i no es van trobar diferències intergrupals post-intervenció. El grup OMS només va millorar en tres escales del qüestionari MAIA (p <0,01). L'anàlisi de contingut de les entrevistes va revelar cinc temes basats en les preguntes formulades: l'adhesió i motivació durant el programa, els inconvenients del programa, l'autoregulació i l'autonomia, l'impacte en l'estil de vida i la consciència interoceptiva. Tots dos grups van coincidir en què ser supervisats per un entrenador personal i rebre feedback constant va facilitar la seva participació. Destacant la personalització del grup del co-disseny, alguns van continuar la pràctica després de la intervenció. Els participants que es van retirar del programa de l'OMS ho van fer a causa de la manca de flexibilitat horària i incompatibilitat del programa amb les seves necessitats i contextos personals.

Conclusió: En conclusió, la perspectiva teòrica i metodològica de la NPE presentada en aquesta tesi, permet actualitzar i personalitzar de forma real les recomanacions d'exercici per la salut per a qualsevol grup de població. Una intervenció personalitzada basada en els principis de la NPE va ser més efectiva per al desenvolupament de la salut mental, la consciència interoceptiva, l'autonomia i la autoregulació de l'exercici en comparació amb una intervenció basada en les recomanacions de l'OMS. Les futures investigacions han d'implicar la col·laboració d'organismes de salut, professionals, investigadors/es i usuaris/àries perquè, des d'aquesta nova mirada de la NPE, es contribueixi a desenvolupar eficaçment la salut de la població.

1. Estructura de la tesi

Tesi en format clàssic amb 1 article annexat

Un total de dos articles publicats (veure final de la introducció) donen suport a l'article original presentat en aquesta tesi. El primer, detalla les bases i el marc programàtic de la Fisiologia de Xarxes de l'Exercici, perspectiva que fonamenta la tesi. El segon, fa una proposta de recomanacions d'exercici per la salut en el context del teletreball, i el tercer, (article original annexat) compara l'eficàcia de dues intervencions d'exercici basades, respectivament, en les recomanacions de la OMS i els principis de la NPE sobre l'estat de forma, la salut mental i el benestar en adults sans. Seguidament, es proporciona informació del article original d'aquesta tesi (article sencer en annexes).

Prescribing or co-designing exercise in healthy adults? Effects on mental health and interoceptive awareness.

- Estat: Article publicat.

- Revista: Frontiers in Behavioral Neuroscience

- Índex d'impacte: JCR: 3,0, Q1 (2022); SJR: 0,98, Q1 (2022).

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2. Introducció

2.1. Justificació de la tesi

La inactivitat i el sedentarisme s'han convertit en greus problemes de salut a la societat contemporània (1–3). Aquesta problemàtica s'ha vist abordada notablement pel creixement de la indústria del fitness, que ofereix una àmplia gamma d'instal·lacions i programes d'exercici per diferents grups de població (4). En aquest context, la selecció d'un programa adequat és una qüestió fonamental que ha sigut examinada per la recerca científica en els darrers anys (5).

En base a aquesta recerca, l'American College of Sports Medicine (ACSM) i l'Organització Mundial de la Salut (OMS) han establert unes directrius concretes per a la prescripció d'exercici en la salut i la malaltia (6,7). És remarcable comprovar que tant l'OMS com l'ACSM coincideixen en fer una recomanació universal amb adaptacions lleugeres segons l'edat i el tipus de disfunció o malaltia de la població. Aquesta recomanació universal inclou l'exercici aeròbic, ja sigui en solitari o combinat amb entrenament de força.

Els programes d'exercici aeròbic i de força han demostrat la seva eficàcia i seguretat en una àmplia diversitat de poblacions (8,9). Tot i això, una revisió sistemàtica dels estudis de prescripció d'exercici ha revelat que, malgrat la majoria presenten resultats positius, hi ha una manca d'evidència substancial i d'estudis d'alta qualitat que avaluïn la seva sostenibilitat en el context quotidià (10). A més, les evidències científiques que donen suport a les recomanacions d'exercici per la salut de l'OMS presenten diverses limitacions teòriques i metodològiques. La concepció de l'organisme que assumeixen és el d'una màquina sofisticada que respon a mecanismes de cibernètica clàssica. Es a dir, que es troba regulada per processadors centrals i circuits de retroalimentació negativa que ajuden a mantenir l'homeòstasi durant l'exercici. Aquest enfocament, si bé ha estat útil per a la comprensió i el disseny d'ordinadors, és massa simplificat per capturar adequadament les propietats dels sistemes vius i la seva interacció amb l'entorn.

Molts sistemes naturals i socials són no-lineals i estan sotmesos a la incertesa i la variabilitat, la qual cosa fa difícil predir-los o controlar-los a partir de mecanismes de cibernètica clàssica. Per determinar els nivells òptims d'exercici o valorar els estats fisiològics, les variables utilitzades sovint no són prou vàlides ni sensibles als canvis. A més, la validesa externa dels estudis que avalen l'evidència científica de les recomanacions de l'OMS presenten importants limitacions metodològiques.

Per tal de millorar l'eficàcia de les intervencions d'exercici resulta necessari revisar i actualitzar les directrius proposades per l'OMS, i fer-ho en base a la concepció de l'organisme com a sistema complex adaptatiu (SCA), amb propietats ben diferenciades de les màquines. En aquest sentit, la Fisiologia de Xarxes ofereix un marc conceptual i metodològic idoni (11,12)

2.2. Origen de les recomanacions d'exercici per a la salut de l'OMS

Amb l'objectiu de reduir la inactivitat física, l'OMS estipula la quantitat d'activitat física (freqüència, intensitat i durada) necessària per obtenir beneficis per la salut i mitigar els riscos per a tota la població. Concretament, el Pla d'Acció Mundial sobre l'Activitat Física 2018-2030 de l'OMS pretén reduir-la en un 15% l'any 2030, a través de 20 accions i intervencions polítiques recomanades (13).

Aquestes directrius, que serveixen com a referència per a la prescripció d'exercici en diversos països i regions (6,14–16), han sigut desenvolupades per comitès d'experts designats per governs i autoritats polítiques responsables de la salut pública. En base a revisions sistemàtiques existents sobre activitat física i salut, els experts escollits elaboren informes que posteriorment són avalats per altres organismes governamentals.

L'edició més recent de les recomanacions d'exercici per a la salut de l'OMS estableix les dosis específiques recomanades per a tot tipus de poblacions, des de les diferents etapes de la vida (infants, adolescents, adults, dones embarassades, postpart, gent gran) fins a pacients amb diverses malalties i patologies cardiovasculars, disfuncions respiratòries, locomotores, endocrines, nervioses, digestives, urinàries, ginecològiques i psicològiques com ansietat, depressió, estrès o conducta alimentaria) (14). Curiosament, tots els grups comparteixen un tipus similars de recomanacions d'exercici (veure taula I).

La universalitat de les directrius es fonamenta en que per mantenir un bon estat de salut és imprescindible treballar dues dimensions essencials del fitness: la resistència i la força. De fet, els exercicis proposats s'estructuren en força, resistència aeròbica, flexibilitat i capacitat neuromuscular. La dosi d'exercici es pauta segons la unitat metabòlica basal (MET), és a dir,. la quantitat d'energia que es consumeix en repòs. Per exemple, la pràctica de ioga està considerada entre -3 METs, caminar a un ritme moderat entre 3-4 METs, nedar lleugerament 4-5 METs, o ciclisme a una velocitat moderada entre 5-7 METs.

Una persona activa ha de realitzar, com a mínim, 150 min d'activitat física d'intensitat moderada per setmana (equivalent a 4 METs durant 5 dies a la setmana, amb sessions d'almenys 10 min de durada. Com que es considera que hi ha una relació dosi-resposta entre càrrega imposada i resultats, per aconseguir efectes més intensos, es suggereix doblar el volum d'activitat (fins a 300 min/setmana) o reduir-lo a 75 min/setmana si l'exercici és més vigorós (20 min d'activitat física intensa, 10 METs, durant 3 dies a la setmana). L'entrenament de la força muscular, realitzat a una intensitat moderada o alta i amb una freqüència de 2 dies/setmana, també s'aconsella per assolir beneficis addicionals per a la salut (14). Tot i que s'inclouen exercicis d'estirament i escalfament, es considera que els seus beneficis encara no estan plenament demostrats. A la taula I es mostra un exemple de les directrius dirigides a diferents grups de població.

Taula I. Recomanacions generals de prescripció d'exercici per a la salut. Exemples adreçats a diverses poblacions.

Adults (18-65 anys)	150 min d'**activitat física aeròbica** d'intensitat moderada o 75 min d'activitat física aeròbica d'intensitat vigorosa , o una combinació equivalent d'ambdues, cada setmana. Activitats d'**enfortiment muscular** 2 dies per setmana.
Dones embarassades i postpart	Almenys 150 min d'**activitat física aeròbica** d'intensitat moderada durant la setmana. Incorporar una varietat d'activitats aeròbiques i d'**enfortiment muscular.**
Persones amb malalties cròniques (hipertensió, diabetis	150-300 min d'**activitat física aeròbica** d'intensitat moderada ; o almenys 75-150 min d'activitat física aeròbica d'intensitat vigorosa. Activitats **d'enfortiment**

tipus 2, supervivents del VIH i del càncer)	**muscular** d'intensitat moderada que involucren tots els grups musculars principals durant 2 o més dies a la setmana. **Programa multicomponent** (força, resistència, equilibri, i coordinació) 3 dies/setmana.
Adults amb discapacitat	150-300 min d'**activitat física aeròbica** d'intensitat moderada ; o almenys 75-150 min d'activitat física aeròbica d'intensitat vigorosa. Activitats d'**enfortiment muscular** 2 dies/setmana. **Programa multicomponent** (força, resistència, equilibri, i coordinació) 3 dies/setmana.
Adults grans (+65 anys)	150 min d'**activitat física aeròbica** d'intensitat moderada o 75 min d'activitat física aeròbica d'intensitat vigorosa, o una combinació equivalent d'ambdues, cada setmana. Activitat aeròbica en episodis d'almenys 10 min i repartida al llarg de la setmana. Activitats d'**enfortiment muscular** 2 dies/setmana complementades amb entrenament de flexibilitat, equilibri i resistència muscular per prevenir caigudes.

Font: Extreta de les recomanacions de l'OMS (14).

Amb el suport d'institucions privades com l'ACSM (7,17), les directrius de l'OMS han estat reconegudes com els "estàndards d'or" en la indústria del fitness que s'alinea amb l'OMS a través de l'eslògan "*some is good, more is better*"(18).

És important tenir en compte els motius econòmics que hi ha al darrera de la connexió entre la indústria del fitness i la salut (19). Aquests interessos es manifesten en campanyes com "Sport is Medicine" (https://www.exerciseismedicine.org/), esponsoritzades per firmes comercials. Les imatges que s'utilitzen en la promoció de la campanya relacionen un cos "ideal" amb l'estat de salut, suggerint l'assoliment d'aquest cos "ideal" mitjançant l'entrenament de força (20,21). La cultura del fitness centrada en l'estètica promou la necessitat d' una quantificació precisa de l'activitat per valorar objectivament les càrregues i els progressos de l'estat de forma. D'aquesta manera, es realitzen inversions significatives en el desenvolupament de cadenes de gimnasos equipades amb màquines de musculació i sistemes de control de càrregues com ergòmetres, rellotges esportius o polseres d'activitat (22) que afavoreixen la quantificació de la despesa energètica (23).

El terme "prescripció", utilitzat en les directrius d'exercici, implica ordenar o decidir sobre una obligació. Adoptat directament de la medicina, s'utilitza en l'àmbit de la salut per designar l'acció d'emetre receptes d'exercici, considerat actualment com a medicina (24). La taula II mostra l'estreta relació entre els dos models de prescripció. De la mateixa manera que el metge prescriu medicaments, el/la professional de l'activitat física i l'esport dissenya programes d'exercici concretant les dosis específiques, els efectes adversos, etc. (25). No obstant, les ordres dels/les professionals no solen ser suficients per generar adherència a l'activitat física i quan l'objectiu final és aconseguir un estil de vida més actiu, no solen ser suficients (26).

Taula II. Aspectes comuns entre la prescripció de medicació i la prescripció d'exercici.

Tipus de prescripció	Medicina	Exercici
píndola	Ibuprofè	Córrer, pedalejar
dosi	1 comprimit de 600 mg cada 8 hores	45 min a intensitat moderada. 3 dies/setmana
durada	10 dies	Tota la vida
precaucions	Malestar estomacal	Si hi ha molèsties, reduir la intensitat per evitar el risc de lesions

Font: Adaptada de Phillips i Kennedy, (27).

De la mateixa manera que la dosi d'un fàrmac no és adequada per a tots els pacients, una dosi universal d'exercici (com ara 150 min/setmana d' activitat física) no és adient per a totes les situacions clíniques i contextos personals (27). Per exemple, una persona sedentària amb múltiples afeccions cròniques podria beneficiar-se significativament d'un petit augment d'activitat física, però podria veure's perjudicada per una dosi que fos massa gran. Una mare treballadora amb tres fills petits a casa no es beneficiarà de la mateixa prescripció d'exercici que una dona de la mateixa edat que no comparteix el mateix context laboral i familiar.

Cada "recepta" hauria de tenir en compte la circumstància única de cadascú, i el seu canvi amb el temps i el context físic i social immediat. Una pràctica descontextualitzada, que promogui una càrrega addicional a la quotidiana, pot augmentar l'estrès. De fet, prendre la píndola d'exercici sense considerar el context individual (com el tipus de treball o l'estat de fatiga) pot incrementar els nivells d'ansietat i estrès en adults i adolescents (28,29).

D'altra banda, hi ha diferències substancials entre prescriure intervencions d'exercici i prescriure fàrmacs. A diferència dels fàrmacs, que solen incidir sobre processos moleculars específics, l'exercici afecta a tots els components i processos de l'organisme d'una manera correlacionada. Alguns autors es refereixen a l'exercici com una autèntica "polipíndola" disponible a baix cost i relativament lliure d'efectes adversos (30). Els seus efectes secundaris i a mig-llarg termini difereixen significativament dels produïts pels fàrmacs (31–33). Per entendre i avaluar la magnitud real dels efectes de la intervenció d'exercici i comparar-la amb la dels fàrmacs, caldria implementar mesures fisiològiques adequades. En aquest sentit, les variables de rendiment no són suficientment informatives de la càrrega interna. Per aquest motiu, és aconsellable l'ús de mesures de connectivitat i variables coordinatives com les que proposa la Fisiologia de Xarxes (34).

Finalment, cal considerar que actualment no és necessari un/a professional per prescriure pautes d'exercici adreçades a cada grup de població o etapa vital. La intel·ligència artificial (IA) proporciona programes d'exercici per a diferents perfils individuals (35,36). No obstant, tant les recomanacions universals de l'OMS com els programes d'exercici generats per l'IA no s'adapten als condicionants i restriccions contextuals canviants que caracteritzen un programa realment personalitzat (37).

2.3. Limitacions metodològiques de les evidencies científiques que recolzen les recomanacions d'exercici per la salut

A banda de partir de supòsits teòrics sobre simplificats, els estudis que donen suport a les recomanacions d'exercici per la salut de l'OMS sovint apliquen metodologies d'investigació inadequades per personalitzar les prescripcions (10,34).

Els dissenys experimentals basats en la **comparació de mitjanes** grupals que contrasten els efectes de les intervencions o teràpia d'exercici amb grups control (sense intervenció o amb un estil de vida sedentari) ofereixen **resultats que no són generalitzables a tota la població**. En primer lloc, les mostres no son representatives de la població diana, sinó que solen estar formades per voluntaris, de manera que els resultats positius dels programes estandarditzats poden estar sobrevalorats (10). En segon lloc, l'efectivitat dels programes d'exercicis provats en **entorns de laboratori** no es poden extrapolar directament a la realitat (6). En tercer lloc, les mitjanes poden emmascarar diferències individuals importants. Mentre que alguns subjectes d'estudi poden presentar resultats positius com a conseqüència de la intervenció, altres poden no tenir cap efecte o fins i tot presentar efectes negatius (38,39). El problema de la generalització de la mostra a la població es resol en els dissenys experimentals a través de **l'estadística inferencial** i el càlcul de probabilitats. No obstant, cal tenir molt present que les diferències estadístiques no son diferències reals i els llindars de significació estadística ($p<.05$, $p<.01$) no suposen barreres per considerar l'existència de diferències reals. Aquestes creences errònies al voltant dels llindars de significació estadística han portat a científics i editors de revistes a privilegiar determinats resultats, distorsionant la literatura i proporcionant interpretacions errònies que afecten a la prescripció d'exercici per la salut entre d'altres (40). Inclús alguns científics han arribat a reclamar que es retirin aquests llindars de significació estadística per evitar biaixos de la literatura (41).

Mentre que el problema de la generalització de la mostra a la població ha sigut àmpliament discutit a la literatura, hi ha un altre supòsit fals menys reconegut que distorsiona la correcta interpretació dels resultats dels dissenys experimentals que comparen mitjanes grupals. Es la suposada: homogeneïtat dels participants de les mostres d'estudi. Aquest supòsit porta a **inferir les variacions intraindividuals** a partir dels resultats de les variacions interindividuals obtingudes per comparació de les mostres d'estudi. L'objectiu principal de la prescripció personalitzada és conèixer els efectes d'exercici a nivell intraindividual i aquests no es poden inferir de resultats intergrupals (42).

Per superar aquests biaixos científics, la NPE suggereix començar per detectar patrons dinàmics de resposta individual, després agrupar els patrons comuns i, finalment, generalitzar aquests patrons a la població diana, discriminant els patrons comuns dels trets individuals (34,37,43). És a dir, generalitzant dels individus a la població en lloc de generalitzar de la població als individus. En conseqüència, les recomanacions personalitzades haurien d'evitar reduir els individus a categories en funció del la seva etapa vital o de la seva patologia perquè les diferències intragrup poden ser enormes.

És important assenyalar també que la variabilitat intraindividual es desenvolupa en el temps i reclama de l'anàlisi de sèries temporals de les variables d'estudi seleccionades. Les avaluacions de l'estat de forma es centren sobretot en variables quantitatives de rendiment o fisiològiques que contrasten **valors màxims** ignorant l'evolució en el temps de les variables estudiades. Per exemple, es considera el consum màxim d'O_2 però no la l'evolució individual del VO_2 amb l'aplicació de càrregues. La dinàmica de canvi de les variables fisiològiques no pot ignorar-se perquè és molt informativa de l'adaptabilitat de l'organisme. De fet, la covariació de sèries temporals que recullen la resposta càrdio-respiratòria en proves d'esforç, semblen ser més sensibles a les intervencions que el propi VO_2 max (44).

Com la variabilitat intraindividual inclou fluctuacions diàries, setmanals o estacionals de la pressió arterial, la freqüència cardíaca o la temperatura corporal, canvis en les condicions de salut, alteracions en els estats emocionals i mentals, i respostes a influències externes com la dieta, l'activitat física o el medi ambient. Tenir en compte aquesta variabilitat és crucial per oferir unes recomanacions d'exercici flexibles i adaptables.

A més, tenint en compte la naturalesa dinàmica i no lineal de l'organisme, es pot donar el cas de que encara que no hi hagin canvis quantitatius substancials en variables de rendiment, petits canvis de volum o intensitat d'exercici suposin un impacte no només quantitatiu, sinó també qualitatiu (coordinatiu) en l'estat de salut o de forma (p.e., provocar una lesió o un estat de sobre entrenament) (45,46).

2.4. La Fisiologia de Xarxes de l'Exercici o *Network Physiology of Exercise*

Per una millor comprensió de la perspectiva que fonamenta aquesta tesi, introduïda al primer article (veure secció 5.1), s'inclou l'escrit enviat a la II edició del Certamen de Divulgació sobre Medicina i Salut, *The Conversation*, 2022.

Si dirigissis la selecció nacional de waterpolo, com triaries les teves jugadores per formar el millor equip de la història? Podries optar per la més forta, la més ràpida o la més experimentada, però això no garantiria l'èxit de l'equip. Un equip es crea a partir de la interacció entre les seves jugadores, no simplement sumant les habilitats individuals de cadascuna. Aquest principi s'aplica també al cos humà, on els seus components cooperen per preservar la salut i garantir la supervivència en entorns variables.

La salut i el fitness són el resultat d'interaccions en xarxa que operen en diversos nivells (personal, social, ecològic) i dimensions (fisiològica, psicològica, emocional). Així doncs, la forma com interactuem amb altres persones, l'entorn i el significat que donem a la vida tenen un impacte significatiu en la nostra salut. A més, la salut també té un component subjectiu, ja que podem estar malalts físicament però sentir-nos saludables, o no tenir cap malaltia objectiva però sentir-nos malalts. Llavors, com podem aconseguir estar i sentir-nos sans i en forma?

No existeix una fórmula única i infal·lible per aconseguir la salut i el benestar físic. La xarxa ofereix múltiples possibilitats d'intervenció, totes interconnectades entre sí. Per estar en forma, no només és suficient tenir un cor fort, pulmons grans i músculs desenvolupats; és necessària una bona comunicació entre aquests òrgans, tal com succeeix en un equip de waterpolo. Quan un òrgan falla, un altre pot compensar-ho, i aquesta capacitat depèn de la seva comunicació en xarxa i de la seva capacitat per establir connexions i sinergies eficaces de manera ràpida.

La Fisiologia de Xarxes de l'Exercici s'ocupa d'analitzar com es coordinen i sincronitzen els components d'una xarxa, tant a nivell horitzontal (dins del mateix nivell, com entre òrgans) com a nivell vertical (entre nivells diferents, com entre cèl·lules i òrgans). Una xarxa saludable es caracteritza per tenir múltiples connexions flexibles que s'adapten i es reconfiguren ràpidament davant de canvis interns, com la fallada d'un component, o externs, com una infecció vírica. En cas de fallada d'un component, la resta de la xarxa es reorganitza per mantenir la seva estabilitat funcional. Per exemple, quan una jugadora s'esgota durant un partit, les seves companyes col·laboren per compensar la seva manca d'efectivitat i seguir sent competitives.

Una xarxa fatigada presenta connexions febles o rígides i poc flexibles entre els seus components, la qual cosa resulta en una baixa capacitat d'adaptació al canvi. Com es pot veure en l'animació del QR, qualsevol fallada en la xarxa que no sigui compensada adequadament pels altres components pot conduir a una sobrecàrrega progressiva que podria desembocar en un col·lapse. Així, la nostra salut i fitness depenen de l'estat de connectivitat de la xarxa i de la seva capacitat d'adaptació davant dels canvis que afecten de manera contínua diversos nivells. Comprendre els principis que governen el comportament de la nostra xarxa fisiològica és crucial per mantenir la funcionalitat.

En lloc de centrar-nos en l'estudi i l'entrenament dels components individuals de la xarxa, ja siguin òrgans o jugadores, resultarà més convenient comprendre com s'estableixen les seves connexions i com es generen sinergies funcionals per ser més eficaços. L'exposició a canvis és crucial per desenvolupar una connectivitat rica i flexible. D'altra banda, la monotonia en els estímuls interns i externs només portarà a una connectivitat més pobra i menys adaptable, insuficient per crear el millor equip de la història.

2.5. Network Physiology of Exercise: vision and perspectives

- **Estat:** Article publicat.
- **Revista:** Frontiers in Physiology.
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- Resum:

Introducció: La Fisiologia ha estudiat les adaptacions a l'exercici sota una perspectiva reduccionista i a través de mecanismes de Cibernètica Clàssica. Aquesta concepció mecanicista de l'organisme s'ha traduït en una comprensió limitada de fenòmens relacionats amb l'activitat física i l'esport

Els supòsits reduccionistes, lineals, estàtics i descontextualitzats que planteja la Fisiologia de l'Exercici han derivat en propostes pràctiques que estableixen relacions causa-efecte entre càrrega i rendiment, objectius d'entrenament poc diversos, metodologies centrades en el professional i relacions de dependència entre professionals i usuaris/àries. A nivell metodològic, les evidències científiques es basen en comparacions de mitjanes grupals de variables aïllades, en la generalització de resultats a la població i la inferència de la variabilitat intraindividual a la interindividual, entre altres.

Objectius: (i) Revisar el paradigma actual de la Fisiologia de l'Exercici i la recerca relacionada; (ii) Introduir les bases teòriques i metodològiques de la Fisiologia de Xarxes de l'Exercici (NPE) en contrast amb les de la Fisiologia de l'Exercici; i (iii) Oferir un enfoc programàtic per a la recerca futura i les aplicacions pràctiques.de la NPE.

Discussió: El nou marc teòric de la NPE, basat en principis de coordinació dinàmica, emergeix per transformar els supòsits teòrics, la metodologia de recerca i les aplicacions pràctiques de la Fisiologia de l'Exercici. Es focalitza en l'estudi de la dinàmica niada de les interaccions verticals (entre nivells, des del genètic fins al social) i horitzontals (entre components del mateix nivell) de la xarxa fisiològica per comprendre els estats fisiològics i els seus canvis amb l'exercici. A través de l'anàlisi de treballs previs, es proporciona una visió de les futures direccions de recerca i les possibles aplicacions pràctiques sobre la prescripció d'exercici per la salut.

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Network Physiology of Exercise: Vision and Perspectives

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The basic theoretical assumptions of Exercise Physiology and its research directions, strongly influenced by reductionism, may hamper the full potential of basic science investigations, and various practical applications to sports performance and exercise as medicine. The aim of this perspective and programmatic article is to: (i) revise the current paradigm of Exercise Physiology and related research on the basis of principles and empirical findings in the new emerging field of Network Physiology and Complex Systems Science; (ii) initiate a new area in Exercise and Sport Science, Network Physiology of Exercise (NPE), with focus on basic laws of interactions and principles of coordination and integration among diverse physiological systems across spatio-temporal scales (from the sub-cellular level to the entire organism), to understand how physiological states and functions emerge, and to improve the efficacy of exercise in health and sport performance; and (iii) to create a forum for developing new research methodologies applicable to the new NPE field, to infer and quantify nonlinear dynamic forms of coupling among diverse systems and establish basic principles of coordination and network organization of physiological systems. Here, we present a programmatic approach for future research directions and potential practical applications. By focusing on research efforts to improve the knowledge about nested dynamics of vertical network interactions, and particularly, the horizontal integration of key organ systems during exercise, NPE may enrich Basic Physiology and diverse fields like Exercise and Sports Physiology, Sports Medicine, Sports Rehabilitation, Sport Science or Training Science and improve the understanding of diverse exercise-related phenomena such as sports performance, fatigue, overtraining, or sport injuries.

Keywords: network physiology, exercise physiology, sport sciences, fitness, sports performance, sports medicine, dynamic networks, complex systems

INTRODUCTION

The human organism comprises various multicomponent physiological systems that interact through various feedback mechanisms across a range of nonlinear feedback mechanisms, operating across spatio-temporal scales to generate complex transient dynamics that continuously adapt to intrinsic and external perturbations. The traditional reductionist approach, employed to investigate physiological systems and their regulatory mechanisms based on classical cybernetics, is insufficient to provide a comprehensive understanding of the structure and dynamics of individual systems and how systems and subsystems coordinate their dynamics across various levels of interaction to generate integrated functions at the organism level. Synchronization and integration among physiological systems is essential to generate distinct physiological states (e.g., sleep and wake, rest and exercise, health, and disease) and, therefore, unraveling the underlying principles of physiological systems integration as a network is crucial to understand how various physiological functions emerge as a result of interaction among such systems. Recent research has shown that physiologic states emerge as a result of a very particular network organization, network topology, and network dynamics of interaction among systems and subsystems (Ivanov and Bartsch, 2014; Ivanov et al., 2017). This dynamic network-based approach to human physiology has the potential to broaden the scope and provide more comprehensive framework of investigations also in the field of Exercise and Sports Physiology and can help address fundamental questions: (i) How muscle fibers within muscle groups and different muscle groups in the human body coordinate their activation during exercise and how this coordination is affected by fatigue? (ii) How organ systems communicate and coordinate as a network to satisfy certain task demands? (iii) How training modifies physiological systems coordination at multiple spatio-temporal scales? (iv) Which are the coordination-related improvements produced by exercise and what are the associated risk factors, the effects on health, and prevention and treatment of chronic diseases? Addressing these questions would have important implications for both Basic Physiology and would open a new frontier of investigations in Exercise and Sports Physiology, Sports Medicine, Sports Rehabilitation, Sports Sciences, and all their different specialties and subfields.

There is an epistemological gap in the scientific research of physiological systems in the field of Sports and Exercise. The prevalent approach is the mechanistic one (Machamer et al., 2000; Bechtel and Richardson, 2010), which aims to uncover the physiological mechanisms responsible for the phenomena under consideration by reducing complex multicomponent system on their parts. The newer, and hence, less developed line of research in the field of Sports and Exercise Physiology is the complex dynamic systems approach, which focuses on the systems complex dynamics with the aim of discovering and formulating general principles on which biological system functionality is based. A crucial distinction between the reductionist and integrative approaches is how they treat the dynamics of biological systems.

Although integrative physiology recognizes the importance of interconnectivity across physiological systems (Sieck, 2017), its research methodologies have traditionally focused on statistical inference of static associations of vertical bottom-up mechanistic causation from the sub-cellular and cellular level to tissue, organ or organism level, and the regulatory functions that govern our physiological state and our health (Head, 2020). The natural evolution of Exercise Physiology toward Genetics and Molecular Biology, has emphasized the collection of integrated analytical approaches that composes the OMICS and contribute to the field of Molecular Exercise Physiology (Wackerhage, 2014; Gomes et al., 2019). As a consequence, there is a wide uncharted territory in research and absence of knowledge in the direction of dynamic characteristics of such vertical integration, as well as the horizontal integration of key organ systems network interactions.

A new field, Network Physiology, has recently emerged to fill in this gap (Bashan et al., 2012; Bartsch and Ivanov, 2014; Ivanov and Bartsch, 2014; Bartsch et al., 2015; Liu et al., 2015b; Ivanov et al., 2016, 2017) and to address the fundamental question of how physiological systems and subsystems coordinate, synchronize, and integrate their dynamics to optimize functions at the organism level and to maintain health. It aims at uncovering the biological dynamic mechanisms (Chen et al., 2006; Ivanov et al., 2009; Bechtel and Abrahamsen, 2010; Bartsch et al., 2012) since it satisfies both the mechanistic requirement of structure and localization (e.g., nodes and edges/links in dynamic networks may represent localized integrated organ systems, subsystems, localized components or processes, and interactions among them across various levels in the human organism) and the requirement of dynamical invariance and generality that is enabled by dynamical systems approach (Meyer, 2020). Organ interactions are essential to produce health, and uncovering the underlying mechanisms of physiologic network dynamics and control is crucial to fully understand the effects of exercise on health, treatment of disease and sports performance.

Disrupting organ communications and their dynamic coordination as a network can lead to dysfunction in individual systems or the collapse of the entire organism during exercise (e.g., fatigue, task failure, and injuries; Hristovski and Balagué, 2010; Balagué et al., 2014b; Vázquez et al., 2016; Pol et al., 2018). Thus, in addition to the traditional approach in biology and physiology that defines health and disease states through structural, dynamic, and regulatory changes in individual systems, the new conceptual framework of Network Physiology focuses on the coordination and network interactions among systems as a hallmark of physiological state and function.

In dynamic networks of physiological interactions, the networks links represent interactions and synchronization between systems and subsystems, and exhibit transient time-varying characteristics (Bartsch et al., 2014; Lin et al., 2016, 2020). A key question is how physiological states and functions emerge out of the collective network dynamics of integrated systems (Bartsch et al., 2015). While network structure may play an important role in generating various states and functions, different global behaviors could emerge due to temporal changes in the functional form of physiologic interactions without reorganization in network topology. This poses new challenges to develop generalized methodology adequate to quantify complex dynamics of networks, where network nodes represent dynamic components of the system and network links reflect different forms of coupling that may change over a range of timescales.

Each physiological system exhibits complex dynamics with a remarkable amount of distinct rhythms that are coupled and coordinated over several magnitudes of timescales. Specifically, previous research has identified the presence of complex temporal organization and long-range power law correlations in the signal output of physiological systems and how temporal characteristics change with transition across physiological states (rest and exercise, sleep and wake, sleep stages, and circadian phases) in the cardiovascular system (Ivanov et al., 1996, 1999a,b, 2001, 2004; Amaral et al., 1998; Ashkenazy et al., 2001; Bernaola-Galván et al., 2001; Goldberger et al., 2002; Kantelhardt et al., 2002; Karasik et al., 2002; Ivanov et al., 2007), the respiratory system (Cernelc et al., 2002; Peng et al., 2002; Suki et al., 2003, 2005), the brain (Linkenkaer-Hansen et al., 2001; Lo et al., 2002, 2004; Beggs and Plenz, 2003; Angelini et al., 2004; Poil et al., 2008; Chialvo, 2010; Schumann et al., 2010; Lombardi, et al., 2012, 2020a,b; Palva et al., 2013; Arcangelis et al., 2014; Liu et al., 2015a), in gait dynamics (Hausdorff et al., 1995, 1997, 2001; Ashkenazi et al., 2002), in wrist motion (Hu et al., 2004; Ivanov et al., 2007), and in the musculo-skeletal system (Kerkman et al., 2018, 2020; Garcia-Retortillo et al., 2020). Investigations in Basic Physiology through the prism of system dynamics have revealed fundamental scale-invariant characteristics that are universal across subjects that encompass a broad range of timescales, indicating the presence of multi-scale mechanisms of physiologic regulation (Ivanov et al., 1998, 2004; Hausdorff et al., 2001; Lo et al., 2002; Kantelhardt et al., 2003; Schumann et al., 2010). Furthermore, every physiological system functions as a dynamic node interacting with other systems through multiple parallel links on a wide range of frequency domains (Bartsch et al., 2012, 2014; Liu et al., 2015b; Lin et al., 2016). The links within a given network adjust the intensity of information transfer (i.e., link strength), so that certain links play the role of major mediators of the interaction between two systems, while other links may present an auxiliary supporting function, thus leading to hierarchically structured organization and profiles of network links strength that are specific for each physiological state. Every physiological state under health or disease (e.g., wake and sleep, sleep stages, rest and exercise) is achieved by means of highly detailed adjustments in the multiple link interactions between dynamical systems – for instance, while during deep sleep brain-heart interactions are characterized by links with identical strength across frequency domains, high-frequency links are the main mediators of brain-heart interactions during wake (Bartsch et al., 2015); furthermore, during the same physiological state, the interaction between different pairs of organ systems can be mediated by dominant links in different frequency domains (Bartsch et al., 2015; Liu et al., 2015b; Ivanov et al., 2017).

In recent years, the Network Physiology framework has been utilized in various fields of basic Physiology and Clinical Medicine, including multiple organ failure and sepsis in critically ill patients (Asada et al., 2016; Moorman et al., 2016), neonatal intensive care (Lavanga et al., 2020; Lucchini et al., 2020), liver disease (Tan et al., 2020), epilepsy and neurological disorders (Lin et al., 2020), diabetes and obesity (Podobnik et al., 2020; Prats-Puig et al., 2020), cancer (Liu et al., 2020), or psychiatry (Bolton et al., 2020), and has the potential for broad applications in the field of Exercise Physiology and Sports Medicine to uncover how the key physiological systems interact pairwise, that is, which links are the major mediators in a given network and how these links adjust their strength with accumulation of fatigue, after a training intervention, or in response to a certain pathological condition (e.g., musculo-skeletal injury and neurodegenerative disease).

The aim of this article is to provide a vision and a new programmatic framework for basic research and practical applications of Network Physiology to Exercise and Sports Science. We propose a new theoretical framework for investigations in Exercise Physiology based on principles and approaches based on Network Physiology and Complex Systems Science. We discuss early works and provide a vision for future research directions in a new emerging field, Network Physiology of Exercise (NPE), utilizing examples of exercise prescription for health and disease, where we focus on exercise recommendations for healthy population and clinical patients (also relevant for sports performance), and we point toward the practical perspectives and future developments in NPE.

EXERCISE PHYSIOLOGY AND NETWORK PHYSIOLOGY OF EXERCISE: CONTRASTING APPROACHES

Figure 1 shows a schematic diagram for the vision of NPE. A hierarchical organization of embedded networks into networks (genetic, tissue, organ, systemic, etc. networks) interact dynamically (horizontally and vertically). Each of them has its own regulatory mechanisms but mutually interact and operate at different levels and timescales (Thompson and Varela, 2001; Tarasov, 2019). Upper and lower network levels are related through circular causality: bottom-up, new components (cells, tissues, organs, etc.), and their properties emerge through a self-organizing process. Top-down, the higher levels constrain the lower ones (Noble et al., 2019; Tarasov, 2019).

The network science-based vision of NPE is in contrast with that of current Exercise Physiology, strongly influenced by reductionism. In this section, we contrast the theoretical assumptions of both approaches focusing on some main misconceptions that affect the understanding of diverse exercise-related phenomena: the adaptive properties of the human organism, the understanding of the physiological states of health and fitness, the objective and principles of exercise training, the assessment of the physiological status, and the role of exercise professionals and users/patients. **Table 1** summarizes the main traits.

From Reductionism to Dynamic Networks Integrative Approach

Exercise Physiology, the most influential discipline in exercise and sports training, has remained resistant to the introduction

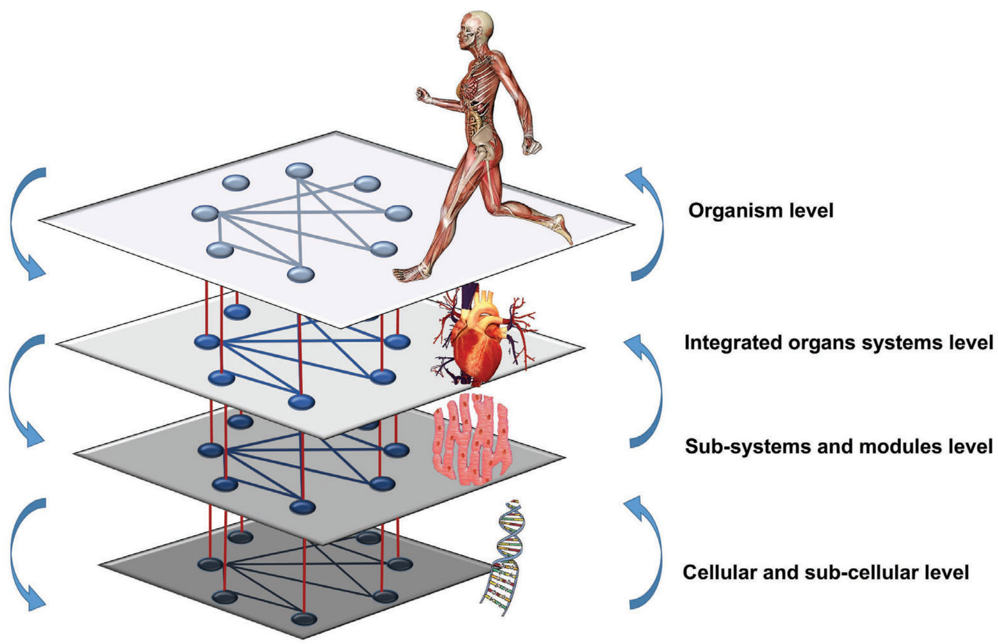

FIGURE 1 | Schematic diagram for the vision on Network Physiology of Exercise. Hierarchically organized physiological network levels interact both horizontally and vertically through circular causality.

of the science of complex systems in biology (Hristovski et al., 2014; Balagué et al., 2016; Pol et al., 2020). Reductionism has dominated the research and has shaped the way of thinking of exercise professionals. To understand any physiological phenomenon, reductionism breaks it down into increasingly smaller parts with the help of technological advances: organisms are dissected, cells isolated, etc. Its influence explains the persistent search for cellular, biochemical, and genetic mechanisms, and the causes of macroscopic phenomena like exercise-induced fatigue, strength or aerobic capacity, etc. For instance, even if there is strong scientific evidence that lactate and other exercise metabolites do not limit exercise performance, a good amount of current research continues to investigate this topic (Hristovski et al., 2014). The fragmentation of fitness in dimensions (endurance, strength, velocity, etc.) and sub-dimensions (maximal strength, explosive strength, etc.), and the isolation of muscle groups with training purposes are also common practices derived from reductionism.

Instead of the usually assumed causal bottom-up effects from micro- to macro-structures and processes, the NPE approach, applying the principle of circular causality, assumes a bottom-up/top-down relationship between micro and macro-components (Noble et al., 2019; Tarasov, 2019). For instance, genes affect organ functions and organ functions constrain gene expression.

Complex Adaptive Systems: Component vs. Interaction-Dominant Dynamics

The understanding of human organisms as complex adaptive systems (CAS), instead of complicated systems (e.g., machines or technical devices), has several theoretical and practical implications on exercise prescription. Contrary to what is usually assumed in Exercise Physiology, in CAS, the behavior emerges from the interaction among components and cannot be explained (or reduced) to any single component. Studying elements of complex systems in isolation is by definition incomplete, as interactions generate novel information that determines the future of elements and thus of the system itself (Gershenson and Fernández, 2012). This dominant interaction dynamics, in contrast with component-dominant dynamics (Van Orden et al., 2003), has been emphasized by several authors (Delignieres and Marmelat, 2012; Vázquez et al., 2016; Almurad et al., 2018). It means that the behavior of CAS cannot be simply explained through the variability of any single component, process, or local mechanism. For instance, exercise physiologists cannot rely on critical quantitative endpoints in cardiovascular, respiratory, metabolic, or neuromuscular systems to explain the limits of performance (Noakes, 2000; Venhorst et al., 2018; Pol et al., 2020) and should reformulate their research hypothesis accordingly.

Complex Adaptive Systems Interact Dynamically, Nonlinearly, and Co-adaptively With the Environment

This means that their interactions change in time, and not only quantitatively but also qualitatively. For this reason, there are neither clearly separable cause-effect or dose-response relations among components nor time-invariant mechanisms and regulation profiles. In Exercise Physiology, the integrative functions are studied within the framework of the traditional control theory, and concepts such as homeostasis, feedback loops and central programmers are usually evoked to describe

TABLE 1 | Contrast between theoretical and practical assumptions of training under Exercise Physiology and Network Physiology of Exercise (NPE) perspectives.

Assumptions	Exercise Physiology	Network Physiology of Exercise
Scientific approach	Reductionism	Network theory
	Cybernetic control theory	Dynamic systems theory
Conception of organism	Machine	Complex adaptive system
Relations	Linear and dose-response	Nonlinear dynamic interactions
Dynamics	Component-dominant	Interaction-dominant
Adaptive properties	Homeostasis	Homeodynamics, spontaneous synergies, degeneracy, and pleiotropy
Training goal (development of)	performance attributes (aerobic and strength)	Functional diversity potential and somatic awareness
Training programs	Pre-defined (universal recipes)	Contextually sensitive (personalized in space and time)
Training and rest dosification	Progressive volume and intensity	Balancing requirements and immediate inner capabilities
Training methodology	Prescription-based	Self-regulation oriented
Training tasks	Imposed aerobic and strength exercises	Contextually meaningful (motivating and co-designed)
Type of exercises	Repetitions	Variations
Evaluation	Cardiopulmonary and strength tests	Connectivity tests
Monitoring	Dominantly objective and external devices	Dominantly subjective and somatic awareness
Professionals/patients and athletes	Prescribers/executers	Co-designers of the process

system regulation during exercise (Lambert, 2005). The behavior predictions of this "engineering" approach are linear, i.e., proportional between inputs and outputs. The basic assumption is that of time-invariant encapsulated processes and regulation profiles. As long as one deals with conceptual, i.e., verbal, descriptive modeling, this approach based on explicit feedback loops seems fine, but when trying to model mathematically more than a couple of interlinked components together, then the system rapidly becomes impossible to treat in terms of explicit feedback circuits and presents serious prediction problems.

In NPE, as exercising individuals interact nonlinearly with their environment, the exercising unit is the performer-environment system (Araújo and Davids, 2016). This means that the individual adaptive responses to exercise are unique and contextually dependent. Feedback homeostatic mechanisms are replaced by the concept of homeodynamics or dynamic stability, i.e., a constantly changing interrelatedness of body components and processes while an overall equilibrium is maintained (Bassingthwaighte et al., 1995).

As nonlinear and history-dependent systems, physiological networks present hysteresis, a phenomenon that explains the delay in a system's recovery of its initial state after a perturbation (Hristovski et al., 2010, 2014; Montull et al., 2020). The study of this phenomenon, a hallmark of complex systems, has revealed the limitations of the widely used linear and proportional regulation models in Exercise Physiology (Abrantes et al., 2012), and has shown the excessively simplified assumptions and artificially created contexts (e.g., in fitness testing). The same exercise perturbation (external load) does not have the same impact (internal load; Fullagar et al., 2019), depending on the previous exercise, the state of the network, and other contextual differences. The area of hysteresis has recently been pinpointed as a new non-invasive marker of exercise stress and tolerance to test the state of the network (Montull et al., 2020).

From Homeostasis of Individual Systems to Emergence and Self-Organization at the Organism Level

Qualitative changes occurring in CAS are the product of a widely ignored property in Exercise Physiology: self-organization. Physiological components and processes acting at multiple levels (from molecules to systems) are spontaneously coupled and there is no need for a template or internal (nor external) programmer to rule the relations. That is, our physiological systems, organs, tissues, and cells change spontaneously through their morphology and function, constrained by evolved genes and their expression, chemical species, natural and social environment, etc. (Sturmberg, 2019). Then, exercise regulation is better understood as a complex, goal-directed, and context-dependent dynamic mechanism adapting to continuous emerging organismic and environmental constraints. In such a framework, nonlinear, i.e., non-proportional, individual physiological changes, and training effects are produced when exposing the organism to exercise and training loads (Hristovski et al., 2010). The authors explain how the same workload, which may promote positive adaptations in a specific context of a given system, may produce overtraining effects and emergent behaviors in another context through coupling, feedbacks, and network interactions.

From Microscopic Functions to Macroscopic Behaviors

The term "training", understood as the process of learning/acquiring specific skills has been recently proposed to be replaced by the term of "synergizing": combining or working together to be more effective (Pol et al., 2020). Synergies are the spontaneously formed structural and functional couplings among components and processes to achieve the main goal in health: keeping the homeodynamics or dynamic stability (Riley et al., 2011; Kelso, 2017; Latash, 2019; Liu et al., 2019). During exercise, synergies operating at diverse scales are continuously re-organized, allowing the reciprocal compensation of components and processes to satisfy task goals. They have circular causal relations with components; that is, components form synergies and those synergies, in turn, govern the components' behavior (Noble et al., 2019; Tarasov, 2019; see **Figure 2**). As shown in the figure, synergies manifest the property of degeneracy; different components can produce the same function and different synergies may be activated to achieve the same task goal (Edelman and Gally, 2001; Latash, 2019). For instance, different motor units cooperate and adjust

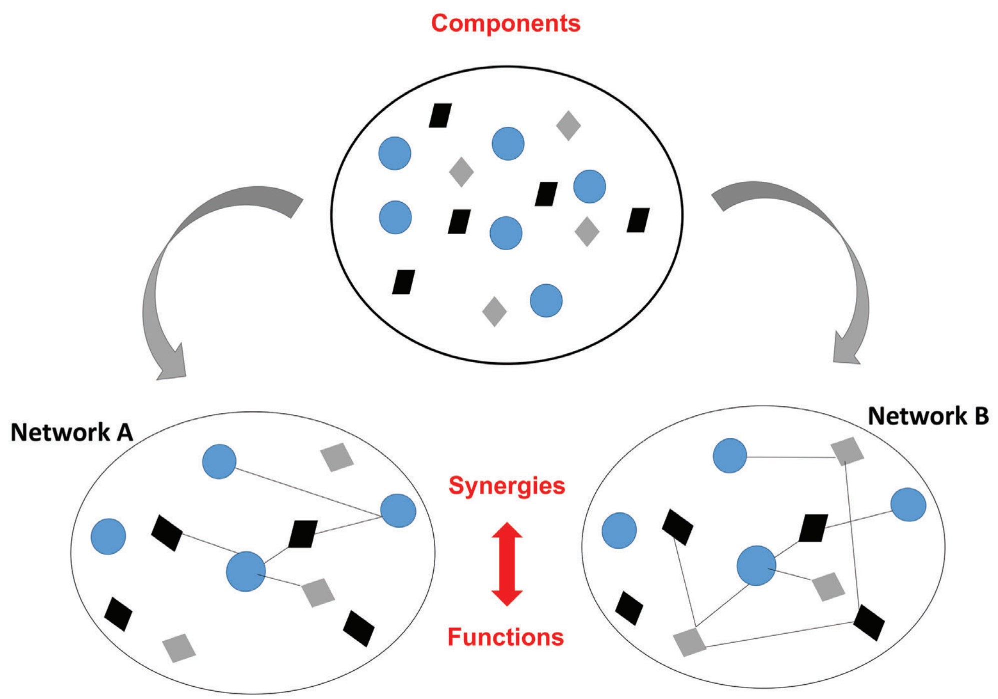

FIGURE 2 | Formation of synergies across levels to satisfy task goals during exercise. Up: representation of different types of components of a certain physiological network. Down: system components, coupled by links, reorganize to form different structural and functional synergies **(A,B)** to achieve the same task goal under changing constraints. Network components are represented by symbols and their links through black lines.

their activation over several timescales to perform an effective or functional motor action over time. The self-assembled, adaptive interactions of CAS underpin also another robustness-enabling property: pleiotropy or multifunctionality, that is, the same components may be assembled to produce multiple functions; for instance, the skeletal muscle has contractile, immunological, and endocrine functions (Pedersen and Febbraio, 2012; Sallam and Laher, 2016). Such properties enable CAS to switch between diverse coordinative states and maintain a metastable dynamic (Bovier and Den Hollander, 2016).

From Developing Isolated Performance Markers/Dimensions to Increased Diversity Potential of Network-Based Measures

Physical fitness is defined as the ability to carry out daily tasks with vigor and alertness, which is better achieved by developing fitness attributes and producing a substantial increase in caloric requirements over resting energy expenditure (American College of Sports Medicine, 2009). In Exercise Physiology, fitness attributes are mostly associated with strength and conditioning. In contrast to this assumption, a new definition of fitness, inspired on theories of biological evolution, has been recently introduced (Pol et al., 2020). The authors sustain that the fittest is not necessarily the fastest or strongest but the most diverse. Accordingly, from a NPE perspective, fitness is defined as the ability to survive in a broad range of contexts, that is, to adapt to socio-psycho-biological challenges (Sturmberg, 2019). In neurobiological systems, dynamic stability, which means survival over long timescales, can only be achieved through a continuous process of complexification, i.e., diversification and specialization (Pross, 2016). Although higher strength or endurance levels imply higher functional (i.e., good variance) diversity, this property cannot be just reduced to these attributes because it embraces multiple dimensions. Furthermore, it may be attained through different processes and in different ways according to the degeneracy property (Edelman and Gally, 2001; Pol et al., 2020).

For instance, a gymnast has more chances to become dynamically stable (i.e., surviving in the competition) by specializing and diversifying the elements of their floor routine. This subsumes diverse functional synergies (reciprocal compensations) coping with diverse and challenging environments (mainly represented by the opponents). In sports, this process of complexification is defined by the athlete's functional diversity/unpredictability potential (Hristovski, 2017; Hristovski and Balagué, 2020), being unpredictability, a relational variable that arises within the performer-environment system and cannot be reduced to the development of strength and conditioning. Accordingly, a change of focus is proposed in fitness programs. Gaining functional diversity, instead of developing aerobic capacity and muscle strength, is the main aim. Diversity can be developed in many ways, not simply through aerobic and strength training, and it is better achieved through varied, non-repetitive training stimulus (Pol et al., 2020).

Figure 3 represents how exercise may modulate communications among physiological systems across levels and timescales leading to changes in functional network connectivity, complexity, and diversity potential of the physiological systems and subsystems promoting health and performance. Physiological organ systems and their components operate at diverse scales (Bashan et al., 2012; Ivanov and Bartsch, 2014; Gosak et al., 2018), modify the number and strength of time-varying (Bartsch et al., 2012, 2014; Bartsch and Ivanov, 2014) couplings, reorganize and reconnect creating new synergies essential to generate distinct physiological states and functions at the organism level (Bartsch et al., 2015; Liu et al., 2015a) and to respond to various task demands or training workloads, thus contributing to the homeodynamics (Balagué et al., 2016; Garcia-Retortillo et al., 2019a). Recent studies have demonstrated that basic physiologic states (wake/sleep and sleep stages) are associated with specific physiological network topology and hierarchical structure of interactions among key organ systems and that physiological networks reorganize with transitions across states to facilitate change in physiological function (Liu et al., 2015b; Ivanov et al., 2017; Rizzo et al., 2020). In the context of exercise, overcompensation response to training (Verkhoshansky and Siff, 2009) may be reflected by increase in coupling intensity and overexpressed connectivity among physiological systems and subsystems leading to reorganization in physiological network structure and dynamics (**Figure 3B**). In contrast, weak or underexpressed connectivity (**Figure 3A**) could be hypothetically associated to sedentarism and injuries (Pol et al., 2018), while excessive exercise could be associated with a transitory underexpression of coupling network connectivity (i.e., imbalance: some processes are overexpressed and others underexpressed; **Figure 3C**). An example of such imbalance is the rigidity and reduction of diversity potential that accompanies exercise-induced fatigue (Vázquez et al., 2016). In a similar way, some pathological conditions (e.g., neuro-muscular disorders) could increase the density and/or strength of interactions among certain physiological rhythms, pushing the system toward a rigid order and reducing the robustness and adaptability to environmental changes (Ivanov et al., 1998, 2001; Stergiou et al., 2006; Stergiou and Decker, 2011).

Health: From Additive Static Systems to Emergent States and Functions From Dynamic Network Interactions

The WHO defines health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (World Health Organization, 2019). This additive definition, including the physical, mental and social dimensions, contrasts with that of Sturmberg (2019) that defines health as an adaptive, subjective, emergent state of the whole person that arises from hierarchical network interactions between different levels: ecological, social, physiological, genetic, etc. (see **Figure 1**). From this perspective, health is the result of dynamic interdependencies between the external environment and the internal physiology. According to the authors, it refers to adapting to socio-psycho-biological challenges and can occur in both absence or presence of objective disease. Due to its experiential and dynamic nature it may change in response to somatic conditions, social connectedness, emotional feelings and semiotic (or sense-making; Sturmberg, 2019). This means

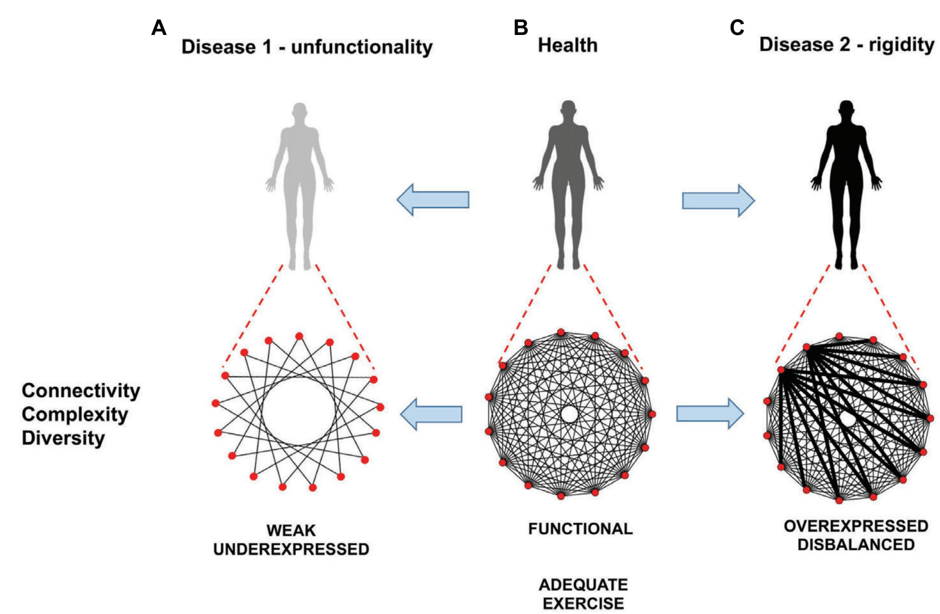

FIGURE 3 | Effects of exercise on functional physiological network connectivity, complexity, diversity. From left to right: **(A)** weak or underexpressed connectivity, corresponding to unfunctional state, **(B)**: functional connectivity, corresponding to healthy, fit state, and **(C)** underexpressed connectivity, corresponding to unfunctional state. Red nodes represent the different physiological network components and the links among them the couplings. The strength of the couplings is illustrated by the thickness of the links.

that a healthy state experience can be achieved in different ways and that there is no unique health state prototype. Thus, effective care must combine strategies centered on the person with those from the NPE perspective.

From Universal Training Program Recipes to Contextually Sensitive Training Criteria

On the basis of current research evidence and simplified assumptions of Exercise Physiology, universal training programs are prescribed for healthy and clinical populations (American College of Sports Medicine, 2009; World Health Organization, 2019). These one-size-fits-all recommendations assume the existence of decontextualized realities (Jones et al., 2017) and ideal or prototypic fitness and health states. However, maximization or minimization of CAS is very hard to define, and consequently to measure and prove due to their context-dependency. Thus, it is recommendable to focus on individual optimality, defined in space and time, and as such, evolving dynamically. Hence, one can speak about larger or smaller adequacy of interventions (see e.g., Chandler, 2018).

The application of the training principles of individualization, specificity, adaptivity, and periodization are a good example of excessively simplified assumptions of Exercise Physiology: (a) The exercise personalization is based on the objective evaluation of a patient's baseline physiological status (American Thoracic Society and American College of Chest Physicians, 2003; Myers et al., 2015); (b) there are specific physiological adaptations to different types of exercise; (c) the adaptation to different intensities, durations, and training frequencies are based on a dose-response relationship, and (d) periodization subsumes the progressive overloading, adequate rest and recovery to maximize the adaptive response (Lorenz et al., 2010).

The principle of training periodization is particularly controversial in pre-established training programs (Kiely, 2018). The assumption that exercise sequencing and scheduling should be based on mechanical training stress ignores, for instance, the neuro-endocrine and bio-chemical consequences of the psycho-emotional stress that overlay training stimuli. This explains why there is no one-to-one mapping between training dose and training effects. The same load that promotes adaptivity may produce overtraining when the context changes (Hristovski et al., 2010). As many personal and environmental constraints change unexpectedly, a long-term training periodization cannot be sufficiently responsive to flexibly adjust to continuous and unpredictable co-adaptive performer-environment processes. In such variable contexts, it seems more adequate that the training process itself, and not the training program, leads and shapes the personalized workload adjustments (Orth et al., 2019). Although several nonlinear periodized prescriptions have proved their higher efficacy, compared to traditional ones, in improving cardiorespiratory fitness (and other important clinical outcomes) for different clinical populations (Jones et al., 2008; Klijn et al., 2013), a further progress in the direction of personalized adjustments is warranted.

Methodological criteria derived from NPE principles (e.g., stability, instability, constraints, change of state, etc.) and defined at multiple levels (Hristovski et al., 2014; Pol et al., 2020) can be used to personalize and coadapt fitness programs avoiding long-term periodization. They compress without fragmenting the huge complexity of dimensions (physiological, psychological, social, etc.), levels, and timescales involved in exercise training (Garcia-Retortillo et al., 2020; Pol et al., 2020).

From Prescribing Exercise Programs to Co-adapting Processes

As long as the training objective is focused on the diversification of complex physiological networks, and not on attaining pre-established fitness outcomes, the training process requires a redefinition of the role of the agents involved in it. Under the NPE perspective, exercise professionals and users/patients/athletes constitute a learning system, in which the exercise professional is not only the manager of the training environment but also a learning component (Orth et al., 2019). Since actions emerge from the performer-environment interaction, the continuous adjustments of workloads and constraints needs the active participation of the users/patients/athletes, which are expected to be not mere executers of the program but their codesigners (Pol et al., 2020). This active involvement of users/patients/athletes in the process supposes a collateral process of developing their somatic awareness (Pol et al., 2018). This skill is essential for capturing personal and environmental constraints changing at fast timescales (e.g., fatigue state, psycho-emotional state; climate, etc.; Balagué et al., 2019) and adapting workloads accordingly. The implementation of adequate subjective assessment tools with pedagogical and exploratory purposes can assist the exercise professional and contribute substantially to healthcare (Pol et al., 2018; Sturmberg, 2019). The implication of the user/patient/athlete as co-designer of the intervention is also crucial to increase their adherence, a key factor for the success of any training program. The exercise professional, in turn, should be mostly focused on selecting and providing adapted, varied, and sufficiently challenging proposals to develop the diversification potential of users/patients/athletes.

From Standardized Tests to Testing Methodologies Based on Functional Diversity

Cardiopulmonary exercise testing is the common assessment of choice for the accurate quantification not only of cardiorespiratory fitness but also for an integrative evaluation of the physiological response to exercise. Additional functional insights are also recommended through assessments of muscular strength, muscular endurance, and balance (American College of Sports Medicine, 2009).

The extracted quantitative variables from cardiopulmonary exercise testing (e.g., VO_{2max}, ventilatory thresholds, etc.) are unable to capture the changes in the network dynamics produced by exercise and training. New methodologies based on continuous and synchronous recordings of multiple physiological parameters are needed to assess the qualitative network reorganization and compensatory synergies accompanying the exercise perturbations.

The assessment of correlation properties in the series produced by physiological parameters allows us to determine the possible alterations of complexity, either toward disorder (in which case correlations tend to extinguish in the series) or toward rigid order (in which case correlations tend to increase). From this point of view, complexity is conceived as an optimal compromise between order and disorder. This dynamic is characterized by long-range correlated series (1/f fluctuations; Delignieres and Marmelat, 2012), which can be detected using fractal analysis methods (Peng et al., 1995). The loss of complexity can be produced either by a decrease of the density of interactions between components or by the emergence of salient components that tend to dominate the overall dynamics (**Figure 3**). In the first case, the system derives toward randomness and disorder, and in the second toward rigidity. Complexity defines a fit state, characterized by robustness (or stability despite environmental perturbations) and adaptation to environmental changes. These relationships between complexity, robustness, adaptability, and health have been well illustrated by Goldberger et al. (2002) in the domain of heart diseases.

EARLY WORKS AND FUTURE RESEARCH DIRECTIONS IN NETWORK PHYSIOLOGY OF EXERCISE

The new NPE assumptions contrasted in "Exercise Physiology and Network Physiology of Exercise. Contrasting Approaches" section change not only the understanding of exercise-related phenomena but also the research questions, the research methodologies and data analysis, the research interpretations, and their practical consequences in diverse fields of knowledge related to exercise and sport.

Considering the interaction of dominant dynamics of CAS, NPE research is focused on the vertical as well as the horizontal dynamic integration of networks (see **Figure 1**). The vertical integration assumes the study of couplings between lower and upper level networks (e.g., genomics and metabolomics networks with tissue networks, organic networks, etc., and vice versa), and the horizontal integration of the study of interactions among network components belonging to the same level (e.g., between organs: muscles, liver, lungs, and brain). To identify and quantify adequately vertical and horizontal dynamic interactions during exercise, new data analysis methodologies should be developed.

Methods applied to study physiological states non-related to exercise (e.g., wake, sleep, and disease) include: (i) cross-correlations of instantaneous phase increments – cerebral autoregulation and stroke (Chen et al., 2006), and migraine (Angelini et al., 2004); (ii) cross-correlations based on local and global detrending (Podobnik et al., 2009); (iii) automated phase synchronization technique – patterns of synchronous behavior between respiratory and cardiovascular systems (Bartsch et al., 2012); (iv) major component analysis of dynamic networks of physiologic organ interactions (Liu et al., 2015b), or (v) the time-delay stability technique - a novel approach to infer and quantify interactions among diverse dynamical systems that studies the time delay with which bursts of activation in the output dynamics of a given physiological system are consistently followed, with constant time delay, by corresponding bursts in the signal output of other systems (Bashan et al., 2012; Ivanov and Bartsch, 2014; Bartsch et al., 2015).

Together with the aforementioned data science methodologies, other methods such as bivariate methods may be useful for analysis of stochastic processes with two macroscopically defined variables. More methods such as multivariate transfer entropy may be applied to interacting components at microscopic level and used for inferring more complex directed network structures (e.g., Novelli et al., 2019). For systems whose important dynamics can be determined by a few dominant oscillatory modes, the method of coupling functions (Stankovski et al., 2017) may provide a relevant determination of causal mechanisms of interaction among components. The Karhunen-Loeve decomposition (i.e., PCA; Carver et al., 2002; Hacken, 2006) may further play a methodological significant role not only in data dimension reduction but also in the explanation of the system's functioning by determining the collective variables that enslave lower placed component processes. Recent theoretical work in this direction (Tarasov, 2019) opens the possibility to methodologically tackle temporally nested and long memory processes with power law behavior. Network measures such as clustering coefficients may provide important information about the structure of the networks since it is simultaneously a significant constraint on the dynamics within the network (Fagiolo, 2007). Future advances in treating problems discussed in this paper may require approaches based on mutually related multilayer and nested networks (Kivela et al., 2014). These approaches could provide rich information about the existence of coherently behaving communities within the network across its layers. This aspect is crucial for indept formal analysis and modeling of systems with nested interacting constraints that dwell on many spatial and timescales (Balagué et al., 2019; Tarasov, 2019).

Further research is required to develop new tests based on interorganic (horizontal) and multilevel (vertical) interactions, to complement the current assessment protocols used to evaluate fitness and the effectiveness of different exercise interventions. A better understanding of the physiological responses to exercise may assist exercise professionals with the selection of the most appropriate and safe exercise interventions. With the aim of uncovering the effects of exercise on the interactions among different physiological systems, future research programs within the framework of NPE should collect data simultaneously recorded from key organs including the brain, heart, or muscle during exercise. High spatio-temporal resolution instruments such as electroencephalography, electrocardiography, electromyography, accelerometry, or 3D MRI are promising tools to reveal important insights and successfully apply the aforementioned data analysis methods.

Early works on NPE have focused on improving the sensitivity to training and detraining of current fitness markers extracted from cardiopulmonary exercise tests. Cardiorespiratory coordination, a novel concept based on the co-variation among cardio-respiratory variables, has been introduced to assess changes produced by different training programs (Balagué et al., 2016; Garcia-Retortillo et al., 2019a), testing manipulations

(Garcia-Retortillo et al., 2017, 2019b; Zebrowska et al., 2020), and nutritional interventions (Esquius et al., 2019). Cardiorespiratory coordination has been determined through a principal component analysis performed on time series of cardiovascular and respiratory variables registered during cardiorespiratory exercise testing (expired fraction of O_2, expired fraction of CO_2, ventilation, systolic blood pressure, diastolic blood pressure, and heart rate) and through the information entropy measures (information compression; Haken, 2006). During exercise, the interacting systems tend to attune their complexities in order to enhance their coordination. However, when the exercise demands increase, coordination among cardiorespiratory variables decrease. The main findings of this set of studies point toward a higher sensitivity and responsiveness of cardiorespiratory coordination to exercise effects compared to isolated cardiorespiratory outcomes, such as VO_{2max} and other gold standard markers of aerobic fitness. More recent research has investigated changes on cardiorespiratory coherence in response to hypoxic exposure and verified its dependence upon fitness status (Uryumtsev et al., 2020). These results indicate that strengthening connectivity among physiological systems provides optimal responses to hypoxic exposure and reflects the adaptive adjustment of the cardiorespiratory system in trained individuals. Furthermore, it has been recently demonstrated that the Network Physiology approach applied to exercise exhibits high sensitivity to quantify the performance of elite athletes participating at Olympic Games and to differentiate between fitness levels of those who win medals and those who do not (Pereira-Ferrero et al., 2019).

Perturbing the dynamic stability of the physiological network through exercise is crucial to test its health and fitness state because it provides a direct information about its adaptivity to changes. NPE methodologies may expand the knowledge on conditions of maladapted physiology provoked by excessive training load without adequate rest, such as overreaching or overtraining syndrome. Since these states result from a non-functional coupling between physiological subsystems (Kreher, 2016) and are not easily recognized through common physiological tests analyzing isolated outcomes (Meeusen et al., 2013), the tracking of changes on inter-organic interactions in response to training may contribute to develop new tools for early detection and prevention of such fatigue-related states. In fact, adaptivity is not necessarily linked to high maximal quantitative values achieved during cardiorespiratory exercise testing. For instance, an athlete affected by an overtraining syndrome will probably reach a high VO_{2max} but their adaptation to training workloads will be impaired. In contrast, the exploration of different features of the network dynamics like stability, instability, critical phenomena (enhancement of fluctuations and critical slowing down), or hysteresis behavior (Hristovski et al., 2014) may provide a rich information about the personal (in space and time) adaptive and qualitative fitness state. These features have been already tested during exercise using kinematic and psychophysiological variables (see Hristovski and Balagué, 2010; Balagué et al., 2014a, 2015; Garcia-Retortillo et al., 2015; Slapsinskaite et al., 2016; Vázquez et al., 2016; Montull et al., 2020) and the approach should be enlarged to physiological data.

Another maladaptive effect linked to a relevant research area that might benefit from NPE methodologies and principles is muscle injuries prevention. Previous research has related the susceptibility to suffer overuse musculo-skeletal injuries with abrupt changes on the connectivity of microinjuries and the concomitant motor coordination reconfigurations within the musculo-skeletal system (Pol et al., 2018). Therefore, given that interorganic reconfigurations might precede changes on a macroscopic level (Balagué et al., 2016; Garcia-Retortillo et al., 2017; e.g., macroinjury), new research programs are needed to develop novel tools capable of identifying and quantifying the interactions between structures and processes in the musculo-skeletal system and other relevant physiological systems. This would be of key importance to detect critical regions of constraints that increase the musculo-skeletal system susceptibility to suffer an injury (Pol et al., 2018).

In relation with the vertical dynamic interaction, future research should focus not only on bottom-up relations (e.g., from genes or exercise metabolites to organism performance) but also on top-down influences (e.g., from organs or motor actions to genes), including the effects of environmental constraints on physiological states, physiological systems, organs, or genes (Alabdulgader et al., 2018; Noble et al., 2019; Sturmberg, 2019). There may be specific social interaction of physiological effects that affects the vertical as well as horizontal integration. Another fruitful direction of research may be the phenomenon of strong anticipation (Stephen and Dixon, 2011) within the vertical or horizontal integrative realm.

Concretely, current main research directions of NPE aim to: (1) investigate how each organ system coordinate and couple its own distinct physiological rhythms, at a range of different frequency domains and over several magnitudes of timescales in response to exercise-induced fatigue and training load (intra-organ interactions), for instance, how different muscle fibers in a given muscle interact with each other and adjust their activation to create an optimal contraction; (2) explore how different muscles synchronize their activation to optimally perform a certain task (inter-muscular interactions); and (3) uncover the mechanisms underlying the synchronized activation among different brain areas and cortical rhythms and distinct key organ systems (e.g., cardiovascular, respiratory, and musculo-skeletal) during exercise (inter-organ interactions).

PRACTICAL PERSPECTIVES

Assessing Patients and Athletes on the Basis of NPE

According to the basic assumptions and current theoretical framework of Exercise Physiology, the physiological assessment of patients and athletes is traditionally focused on the evaluation of quantitative markers extracted from isolated variables and functions. Such markers provide little information about the coordinated activity and synergies of the physiological systems that are essential to generate behavior at the organism level and appear to not be sensitive and sufficiently responsive to training effects (Balagué et al., 2016; Garcia-Retortillo et al., 2019a), fatigue (Garcia-Retortillo et al., 2017), or nutritional interventions (Esquius et al., 2019), as well as to the prevention and diagnosis of common dysfunctions among athletes (e.g., states of overtraining, injuries, etc.; Meeusen et al., 2013). The majority of investigations in Exercise Physiology utilize static measures (maximal, averages, and threshold values), and the dynamic component of physiological processes is neglected. The significance of gradual increase or decline of physiological parameters during exercise and the nonlinear effects they produce on physiological networks have not been explored from an Exercise Physiology perspective.

According to the interaction-dominant dynamics of neurobiological systems, an NPE approach may prove to have larger potential to evaluate the fitness and training states on a coordinative basis and inform more accurately about the risks of dysfunctions. In this line, the NPE-based assessment has two main objectives: (a) evaluation of physiological networks structure and dynamics, and their evolution in time during and after acute and chronic exercise, and (b) evaluation of the responsiveness of the physiological network interactions to exercise perturbations. The first objective may use connectivity, modularity, causality, and synergy measures (Tognoli, and Kelso, 2014; Varona, and Rabinovich, 2016; Pol et al., 2018), while the second objective would require the detection and quantification of adaptive properties of the physiological network (e.g., stability, metastability, instability, critical behavior and fluctuations, critical slowing down, flickering, and other phenomena such as hysteresis and relaxation time after perturbation) that can be used as coordinative markers of interactions among systems during exercise-related states and functions (Hristovski et al., 2014).

The development of adequate technology of wearable devices, which are able to provide continuous and synchronous recordings (time series) of selected coordinative variables (order parameters) extracted from different physiological levels, is needed to study physiologic network dynamics. Computational intelligence methods, comprising algorithms inspired by nature (Fister et al., 2015) and robust methods able to infer couplings among diverse systems with different type of dynamics (oscillatory, multiscale, deterministic or stochastic, linear or nonlinear) that communicate with time-varying bursting activity (time delay stability; Bashan et al., 2012), could be successfully applied to design future functional evaluation tools based on NPE principles. Such algorithms can be implemented in modern mobile devices supplemented with EEG, EMG, and ECG sensors that are able to determine interorganic interactions during exercise testing. Until then, the availability of continuous recordings in laboratory settings of behavioral variables (e.g., extracted from kinematic or phenomenological data) as order parameters that contain integrated information of all physiological levels can be used to detect modularity in vertical and horizontal integration of the network.

Current Limitations of Exercise Recommendations for Health and Disease

Principles of training derived from Exercise Physiology have remained largely impervious to the transdisciplinary and holistic insights emanating from complex systems approaches (Pol et al., 2018; Fullagar et al., 2019). In this section, the practical perspectives derived from the change of theoretical assumptions and research directions of NPE are illustrated through an example of exercise recommendations. Limitations of current guidelines of exercise prescription in health and disease are reviewed on the basis of NPE with the purpose of contributing to provide safer and more effective practical issues.

Physical activity is taking on an increasingly key role in the prevention and treatment of multiple chronic diseases, health conditions, and their associated risk factors. Despite its well-known health benefits, physical inactivity is considered a global pandemic and has been identified as one of the four leading contributors to premature mortality (American College of Sports Medicine, 2009). Governmental, academic, and research institutions: international organizations; sport associations; and the private sector recommend physical activity as part of a healthy lifestyle and for the prevention and treatment of a long list of chronic diseases. Overall, strong scientific evidence demonstrates that, compared to less active adults, individuals who are more active have lower rates of all-cause mortality and exhibit a higher level of cardiorespiratory and muscular fitness (Green et al., 2008; Wilson et al., 2016). New advances in precision medicine research show the beneficial effect of regular exercise at molecular, cellular, and whole-body levels (Friedenreich et al., 2016). However, there is limited research understanding exercising individuals as networked embedded systems and a clear absence of knowledge regarding the effects of exercise on the interactions among physiological systems.

Almost all studies testing the benefits of exercise for healthy persons and clinical patients closely adhered to the exercise guidelines of World Health Organization (2019) and American College of Sports Medicine (American College of Sports Medicine, 2009). Overall, the recommendations are similar for both healthy and clinical populations with few adaptations in function of the age and type of disease. The situation is not different in sports performance domain, where training recommendations for "optimal" (e.g., maximal) adaptation are proposed (Mujika et al., 2018).

Aerobic activity and strength training, prescribed as basic medication, are the core of programs addressed to healthy persons and clinical patients. Other type of activities related to flexibility such as Yoga or Pilates, which allow the improvement of range of motion and balance, are considered complementary. The recommendations are similar for Alzheimer's disease, aneurysm, asthma, atrial fibrillation, bleeding disorder, blood lipid disorders, cancer, chronic kidney disease, chronic liver disease, chronic obstructive pulmonary disorder (COPD) depression or anxiety, heart failure, heart valve disease, HIV/AIDS, hypertension, fibromyalgia, inflammatory bowel disease (IBD), low back pain, mobility limitations, osteoarthritis, osteoporosis, overweight/obesity, pacemaker, Parkinson's disease, peripheral arterial disease, prediabetes, pregnancy, rheumatoid arthritis, and Type 2 diabetes. Small load adjustments, in combination with some complementary practices, are recommended according to the specific disease.

Aerobic exercise, either alone or in combination with resistance training, at a moderate intensity (50–75% of a predetermined physiological parameter, typically age-predicted heart rate maximum or reserve), performed in two to five sessions per week with bouts equal or higher than 10 min is the general recipe. Ten to sixty minutes per session, with the ultimate objective of achieving at least 150 min/week is the minimum exercising time. Because of the assumed dose-response relationship, for more intense outcomes, the exercising time can be extended to 300 min/week or reduced to at least 75 min/week if the exercise has a more vigorous intensity. Strengthening activities performed at moderate or high intensity and involving all major muscle groups and practiced 2 days a week provide additional health benefits.

Despite the adoption of a relatively homogeneous prescription approach, aerobic and strength training have been, for the most part, associated with benefits across a diverse range of populations (e.g., Bishop et al., 1999; Voisin et al., 2015; Flannery et al., 2019; Klil-Drori et al., 2020; Maestroni et al., 2020). On this evidence, it is assumed that a standardized, largely homogeneous exercise prescription that adopts a conventional approach is safe, efficacious, and therefore sufficient.

Even though most studies present favorable results, systematic reviews and metaanalysis on exercise prescription point to the lack of high-quality studies showing the sustainability of standardized programs (Sørensen et al., 2006) and the need for personalizing the recommendations (Zimmer et al., 2018). The dominance of research based on comparisons of group data means evaluating quantitative changes of isolated variables in lab conditions is clearly limiting the application of a precision exercise medicine approach (Balagué et al., 2020).

Individuals respond and evolve in distinctive ways to standardized training programs (Mann et al., 2014), showing patterns of variability that are not captured by models based on statistical averages. Which people undergo positive effects? Average values mask inter-individual differences - while some individuals respond with big positive effects, others have even detrimental effects. In addition, the attention in most evidence-based medicine and in particular in physical fitness research is almost exclusively restricted to inter-individual variations, neglecting intra-individual time-dependent variations (within each individual) which are better captured through time series recordings (Rose et al., 2013). As there is no equivalence between inter- and intra-individual variability, implementing precision medicine to exercise prescription requires focusing on this neglected time-dependent variation within single individuals. Only such recursive techniques allow personalizing treatments in place and time (Molenaar, 2004; Nesselroade and Molenaar, 2010).

The validity and reliability of tests based on inter-individual variability cannot be generalized to individual assessments of non-stationary processes like training and, thus, cannot provide the basis for individual counseling. The problems related to the biological and measurement variability of gold standard fitness markers like $VO_{2\ max}$, used in the evaluation of aerobic programs, have been widely discussed (Beltz et al., 2016). In fact, new variables of study, based on the covariation of time series of cardiorespiratory variables, have shown more sensitivity to training interventions than VO_{2max}. (Balagué et al., 2016; Garcia-Retortillo et al., 2019a).

Another problem of current research on exercise prescription is derived from the bench to bedside approach. Numerous physical and social environmental factors affect fitness and health (World Health Organization, 2019) and the application of exercise programs tested under lab conditions may have a very different impact in real contexts. Motor actions emerge from the individual-environment interaction and, systematically, different patterns will emerge for different individuals (Araújo and Davids, 2016; Pol et al., 2020). Assuming that the behavior is stable, the available experimental models ignore the influence of context, focusing on averages to reveal "true" behavior. An 18-year longitudinal study has shown that comparable amounts of physical activity can lead to different effects on fitness or health status and have underlined the importance of contexts, content, and purposes of physical activity when health or fitness benefits are addressed (Schmidt et al., 2017). Accordingly, adaptation, not only from person to perso, but from moment to moment in space and time, is of utmost importance to produce effective results (Sturmberg, 2019).

Although systematic reviews and metaanalyses indicate that exercise therapy following a generic prescription is safe, tolerable, and efficacious (at improving symptom control outcomes), caution is recommended when interpreting these data: (1) the effects of exercise therapy are usually compared against a non-intervention control group with a sedentary lifestyle of recognized deleterious consequences, (2) metaanalyses and systematic reviews do not reduce but may enlarge the bias of studies that compound it (Weir et al., 2016).

Finally, research methodologies may also need to be improved to contribute to the development of personalized recommendations. The use of statistical inference techniques without enough criteria in available fitness research has produced a false belief that a significant result reflects the reality (Hristovski et al., 2017). This belief has led scientists and journal editors to privilege statistically significant results, thereby distorting the literature and leading to wrong interpretations (Wasserstein and Lazar, 2016; Amrhein et al., 2019). In research, when the posed question is wrong, multiple pathways cannot be detected initially because the alternatives are invisible to statistical techniques that rely on averages to characterize individual responses (Rose, 2016). Finally, systematic reviews do not solve the problem but may even make it worse because, rather than eliminating the bias, they compound it (Weir et al., 2016).

The significant benefit of a generically dosed exercise on heterogeneous populations reflects the remarkable pleiotropic physiological impact of exercise. In this sense, it is warranted to investigate further the therapeutic properties of exercise medicine to reveal its whole potential role in healthcare. Although it is still not known whether alternative prescriptions adopting a more personalized approach will confer superior efficacy to exercise treatments, several efforts have pointed toward this direction (Jones et al., 2017). In fact, exercise scientists are continuously exploring the tenets of performance to refine and personalize exercise training with the aim of minimizing injury and maximizing benefits.

Some Hypotheses for Future Applicative Research

Due to safety reasons, the current standardized training programs addressed either to healthy individuals, clinical patients, and athletes require the controversial quantification of the relative exercise intensity (Jamnick et al., 2020). And, accordingly, the use of ergometers and strength machines. These technical devices, mostly found in fitness facilitie where healthcare providers and trainers use to refer their users/patients/athletes, reduce the physical activity to cyclic (walking, running, stepping or cycling) and repeated local body movements. In such context, diversity is mostly minimized to volume and intensity changes. Although varying the volume and intensity of exercise increases the diversity potential of individuals, varied activities in natural environments, highly recommendable (Brymer et al., 2020) may help to enhance further this potential. As pointed by Hristovski and Balagué (2012), such open-air activities (mountain climbing, swimming in the sea, etc.) embed performers in a multi-time-scale fluctuation regime of resistance that provides high adaptive effects on body functions. Accordingly, the authors propose to implement in exercise machines (e.g., cycle ergometers, rowing machines, vibrating platforms, steppers, etc.) a multi-time-scale stimulator system to manipulate the variability dynamics and simulate the fractal dynamics found in nature.

In fact, the growing number of fitness specialties (46 in the 2020 ACSM's Worldwide Health and Fitness Trends Survey) is a proof that many types of activities, not only those based on cyclic or repetitive movements, may contribute to fitness and health development. In particular, those activities chosen by users/patients/athletes and intrinsically motivating, if adequately adapted by an exercise professional (introducing progressively new challenges), may favor the adherence to practice (Balagué et al., 2020).

Intelligence in CAS has been recently described as a tendency to evade and escape states of reduced fitness, that is, states of reduced functional diversity potential (Hristovski and Balagué, 2020). This refers to richness of functional synergies and also fast recovery time after a perturbation (see hysteresis behavior of section CAS Interact Dynamically and Non-linearly, i.e., Co-Adaptively, With the Environment). The intelligent behavior may be expressed at diverse levels. For instance, bouts of exercise produce acute fatigue that temporarily decreases the diversity potential of the organism. However, the cell or organism reacts by a temporary increase of the diversity potential anticipating the possible future incoming perturbations. These types of biological behaviors have been modeled as strong anticipation phenomena (Dubois, 2003; Stepp and Turvey, 2010). These exercise effects can particularly compensate the tendency of aging and disease to reduce the diversity potential (Yogev et al., 2007; Rutenberg et al., 2018).

The growth of intelligence requires regular coupling to challenging and stimulating environments to evade the temporary stalemate, which may, on longer time scale, turn into decreasing functional diversity potential (Hristovski and Balagué, 2020). On the other hand, the diversity potential can be reduced due to unexpected perturbations (e.g., the pandemia effects) and the property of biological intelligence is to escape quickly from it through the creation of new synergies which may include new dimensions, not only those related to exercise modalities. In fact, exercise is not the only intervention that may increase the functional diversity potential and/or evade its reduction. Healthy diet, stress reduction, inspiring intellectual work, music, art, meditation, etc. may all contribute to it.

As health and fitness have also subjective dimensions (Sturmberg, 2019), they can be satisfied in multiple idiosyncratic personal ways. This means that the individual satisfying diversity potential is also associated to a subjective experience of wellbeing, and this experience can be recovered in many different ways due to available multidimensional compensations.

Some long-lasting personal or environmental constraints may produce a cascade of long-lasting effects on physiological levels (Balagué et al., 2019) and the response to physical activities may change according to it. Due to the multidimensionality, context-dependency and subjectivity of health and fitness, a personalized exercise recommendation may prove to be more adequate than current standardized exercise programs addressed either to healthy individuals or clinical patients.

It may become recommendable to reorient the main aim of prescribed exercise medicine toward gaining diversity through the development of multidimensional and multiscale synergies. Exercise dosage and formulation, as occuring in personalized medicine, may be adapted accordingly. The formula of an active life with varied stimulus, preferably at open air (Ryan et al., 2010), would then be shown to be more adequate than reducing the physical activity to 75–150 min/week repeating exercises.

As synergy formation is better captured through the interactions among the involved components and processes, variables related to connectivity (number and strength of couplings) can be suitable to test the exercise program effects. Because components of the network cooperate to accomplish the common fitness goal, if the number and strength of couplings is reduced, other components of the network may become overwhelmed and the system may respond less effectively to perturbations, bringing about dysfunction and increased susceptibility to injuries (Pol et al., 2018).

Exercise, in turn, having a profound impact on human metabolism (Koay et al., 2020), may produce very relevant perturbations on the network dynamics at multiple levels (see **Figure 1**), and thus, provide an accurate information about its resilience and antifragility of the organism, key properties to inform about its state. In summary, the NPE approach may transform not only the criteria for exercise prescription but also the comprehension of other fields of knowledge, typically studied under the framework of Exercise Physiology like functional evaluation, injury prevention or limits of performance. It also may provide a new understanding of many exercise-related phenomena as fatigue, overtraining, injuries, etc. currently influenced by a reductionist scientific approach.

CONCLUSION

Current Exercise Physiology, deeply influenced by reductionism, is limiting the understanding of exercise-related phenomena and hampering practical applications to sports performance and exercise as medicine. Integrative Exercise Physiology approaches, methodologically based on statistical inference techniques and focused on timeless vertical, bottom-up mechanistic causation (from the sub-cellular and cellular levels to organ and systemic functions), are not sufficient to improve substantially the current state of physiological research.

Inspired by the new field of Network Physiology and Complex Systems Science, NPE emerges to transform the theoretical assumptions, the research program and the current practical issues of current Exercise Physiology. It focuses the research efforts on improving the knowledge of the nested dynamics of the vertical network interactions and, particularly, the horizontal integration of key organ systems. Through the application of novel methods and approaches derived from recent advances in Network Theory, Nonlinear Dynamics, Computational and Statistical Physics, and Biomedical Informatics, it seeks to provide insights into Basic Physiology itself as well as for Exercise Physiology.

The critical view on the current one-size-fits-all approach of exercise prescription in health and disease, in contrast with a new proposal based on complex systems and NEP principles, illustrates the potential practical impact of the approach, which aims to provide: (a) a theoretical framework to address problems and challenges in Network Physiology, and particularly, in NPE, (b) data-driven discoveries of the basic physiological laws and control mechanisms that underlay network interactions for various states under both healthy and pathological conditions with focus on Exercise Physiology and Sports Medicine, and (c) a forum for developing new methodologies, a vision and a programmatic approach on applications of NPE. In this fashion, more qualitative research directions in Exercise Physiology may be developed and an original and fertile research program can emerge in the near future.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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- Resum:

Introducció: El teletreball està associat amb un comportament sedentari que pot afectar negativament l'estat de salut. Les recomanacions d'exercici basades en receptes universals que es centren en desenvolupar determinats atributs físics, com són la resistència aeròbica i la força, poden resultar insuficients o inadequats per promoure un teletreball saludable. Des de la perspectiva de la NPE es proposa un canvi de rols tant dels professionals con dels usuaris/àries, i uns criteris d'intervenció personalitzats enfocats a desenvolupar el potencial de diversitat funcional dels usuaris/àries.

Objectiu: Proposar recomanacions d'exercici personalitzades per mantenir un estil de vida saludable en el context del teletreball.

Discussió: Es discuteixen alguns mites relacionats amb les recomanacions ideals o úniques relacionats amb l'exercici i la postura ideals, i la contribució de les tecnologies i aplicacions informàtiques recents per a prescriure exercici i avaluar la forma física. En base a la NPE, s'elaboren criteris d'intervenció personalitzats adaptats al teletreball com són la participació activa de l'usuari/a en el procés, la selecció d'activitats basades en les motivacions personals o l'exploració de noves formes de moviment per reduir el temps d'immobilitat. Per últim, es promou la consciència interoceptiva per promoure que els usuaris/àries siguin capaços d'auto-monitoritzar i autoregular les càrregues d'una manera més efectiva.

sustainability

Perspective

Healthy Teleworking: Towards Personalized Exercise Recommendations

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Abstract: Home-based teleworking, associated with sedentary behavior, may impair self-reported adult health status. Current exercise recommendations, based on universal recipes, may be insufficient or even misleading to promote healthy teleworking. From the Network Physiology of Exercise perspective, health is redefined as an adaptive emergent state, product of dynamic interactions among multiple levels (from genetic to social) that cannot be reduced to a few dimensions. Under such a perspective, fitness development is focused on enhancing the individual functional diversity potential, which is better achieved through varied and personalized exercise proposals. This paper discusses some myths related to ideal or unique recommendations, like the ideal exercise or posture, and the contribution of recent computer technologies and applications for prescribing exercise and assessing fitness. Highlighting the need for creating personalized working environments and strengthening the active contribution of users in the process, new recommendations related to teleworking posture, home exercise counselling, exercise monitoring and to the roles of healthcare and exercise professionals are proposed. Instead of exercise prescribers, professionals act as co-designers that help users to learn, co-adapt and adequately contextualize exercise in order to promote their somatic awareness, job satisfaction, productivity, work–life balance, wellbeing and health.

Keywords: exercise prescription; health; fitness; sedentary behavior; posture; affordances; somatic awareness; exergames

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1. Introduction

Coronavirus (COVID-19) pandemic has produced a huge social and environmental impact on our lives, promoting organizational and behavioral changes with important implications for our lifestyle and our health status. One of the most outstanding is the proliferation of home-based teleworking, associated with sedentary behavior [1] and stress disorders [2].

The American College of Sports Medicine (ACSM) and The World Health Organization (WHO) recommend a physically active lifestyle, suggesting that adults participate in at least 150 to 300 min of moderate-intensity (3–6 METs), or 75 to 150 min of vigorous-intensity (>6 METs), or more for additional health benefits, of aerobic physical activity per week, together with strength exercises, to reduce the risk of chronic disease, including cardiovascular disease, type 2 diabetes mellitus, and certain types of cancer [3,4]. Such general exercise recommendations are addressed to healthy persons and clinical patients with multiple diseases and a wide age range. Following a one-size-fits-all approach, these recommendations have been recently questioned for: (a) reducing fitness to aerobic and strength exercises, (b) proposing a linear dose–response (exercise-benefits) relationship, and (c) their lack of personalization [5]. Systematic exercise prescription reviews reveal that even though most studies present favorable results applying the exercise programs proposed by the aforementioned guidelines, there is a lack of evidence in several fields, a lack of high-quality studies [6] and a need for personalized recommendations [7].

Health and fitness concepts have been recently redefined based on a network physiology approach [8]. Sturmberg et al. [9] define health as a dynamic emergent state arising from nested networks interactions, and Pol et al. [10] define fitness as the capacity to survive in a broad range of contexts and point out that such capacity cannot be reduced to endurance and strength dimensions as proposed by current ACSM and WHO main guidelines. In fact, at a more general level, some authors have related fitness with the concept of intelligence, understood as the ability of systems to evade and escape states of reduced possibilities by creating functional compensatory synergies in dimensions other than those affected by reduced possibilities [11]. Under the framework of the Network Physiology of Exercise, it has been proposed that an adequately personalized exercise may promote the creation of functional synergies and healthy physiological network connectivity, characterized by functionality and flexibility, while a sedentary lifestyle may lead to dysfunctional, poor and weak connectivity [5].

In agreement with this new conception of physical fitness, the term exercise is used here in a wide sense. It includes all types of physical activities, not only those planned and structured pursuing the specific goal of improvement or maintenance of physical fitness [3]. Table 1 is summarizing and comparing some main characteristics of exercise recommended from an Exercise Physiology perspective, and from a Network Physiology of Exercise perspective.

Table 1. Comparison between exercise characteristics from an Exercise Physiology perspective and from a Network Physiology of Exercise perspective.

Characteristics	Exercise Physiology	Network Physiology of Exercise
Main goal	Calorie expenditure Aerobic endurance and strength development	Functional diversity potential development
Recommendations	Universal	Personalized
Method	Programmed repetitions	Challenging variations
Dose/intensity	Preprogrammed	Contextually co-adapted
Practice	Monotonous, boring	Enjoyable, motivating
Monitoring	Based on technical devices	Based on somatic awareness
Professionals role	Prescribers	Co-designers
Users' role	Executers	Co-designers

As health is a unique, individual adaptive state, the subjective dimension of health status plays a crucial role in a network understanding of health and disease [9]. In this sense, the subjective experience of health and illness (or poor health) can occur both in the absence and presence of objective disease. This distinction highlights the dynamic emergent nature of health and disease and indicates that in such a subjective scenario, the development of an adequate somatic awareness in individuals is a key element for safe exercise personalization (dose, type of exercise, etc.).

Scientific evidence has shown that regular exercise does improve not only the physical but also the psycho-emotional status, contributing to reduce negative emotion, relieve fatigue, improve sleep quality, and prevent cardiovascular and cerebrovascular diseases, among others [12]. Most of the studies testing the benefits of exercise on healthy people and clinical patients apply exercise protocols and standardized programs based on WHO and ACSM guidelines [3,13] and training recommendations [14]. Average intragroup values mask interindividual differences and neglect context-dependent variations within single individuals [15–17], and thus, cannot be applied to individualized exercise prescriptions [5].

In line with personalized exercise medicine, it has been proposed to reorient the main aims of exercise prescription, and accordingly, to redefine not only the roles of health care exercise professionals but also the user/patient role [12]. Particularly, it has been suggested to develop the autonomy of users/patients through their active involvement in the co-design of exercise proposals and the development of their somatic awareness. The selection of the type of activity, taking into account what is meaningful and attractive for the user, increases adherence to the practice, and periodization based on self-regulation and self-monitoring guarantees healthy and safe practices. As different internal and external constraints influence the individual mind-body states at very fast timescales [18], and these fast changes are hard to be captured through conventional monitoring systems, the development of somatic awareness [10,19] of users/patients is crucial. It may help to regulate and adjust, on a daily basis, active and resting periods, frequency, intensity, duration, etc., of exercise to promote healthy mind-body states.

We claim that education on self-regulation of psycho-emotional and physical states is essential to promote health and wellbeing during home-based teleworking. This requires that healthcare professionals guide the population from dependency to autonomy through the redefinition of fitness states, the aims and focus of the home-based exercise, co-adaptive and co-learning processes and the development of somatic awareness among users/patients. There is no universal way to reduce a sedentary lifestyle because there are huge interindividual differences, and personal contexts are continuously changing. New contexts suppose new challenges and new possibilities for learning and promoting creative behavior [20]. In this paper, we aim to propose, under the Network Physiology of Exercise approach, some personalized exercise medicine recommendations for keeping a healthy lifestyle under home-based teleworking conditions.

2. Home-Based Teleworking, Sedentary Lifestyle and Ideal Postures

Home-based teleworking is a form of work at home using information and communication technologies as support [21]. Working for prolonged periods with a computer, especially at home, is associated with a sedentary lifestyle, static and constraining posture, repetitive movements and extreme positions of the forearm and wrist [22].

Sedentary behavior includes all the activities that do not increase energy expenditure above resting levels, such as sleeping, sitting, lying down, and other forms of screen-based entertainment [23]. Such low levels of physical activity can have negative effects on health, wellbeing and quality of life [24]. Over the past five decades, jobs and occupations have increased the amount of seated technical work or desk-based office work [25]. A systematic review reveals that people with more active jobs had lower all-cause or cardiovascular disease mortality risk than those with jobs that involved mostly sitting [26]. A large-scale prospective cohort study in 220,000 Australians published an association between sitting and all-cause mortality across sexes, age groups, body mass index and physical activity levels [27]. Despite knowing how harmful it is to our health, we spend most of our daily time sitting. Offices, cinemas, cars, schools and restaurants are filled with chairs affording sitting. Standing, in contrast, is considered uncomfortable and even used in the past as a punishment (e.g., for children in schools).

Since the middle of the past century, changes in physical, economic, and social environments (transport, communication, workplace environment, and domestic entertainment technologies) have deeply changed our exercise habits. For such reason, moderate to vigorous exercise recommendations and physically active transportation has been recommended for the adult population [3]. One hour of vigorous exercise most days of the week, even if complying with the minimum of public health guidelines, cannot compensate fifteen hours of non-exercise awake time per day during which sitting is the predominant stance [28]. Sedentary comes from “sedere”, which means “to sit”. As the human body is made to be in frequent motion, sitting many hours a day, day after day, has widely recognized negative effects on health (reduced insulin sensitivity, impaired functioning of HDL cholesterol). This is why the program of sitting less and moving more has been recently promoted [29].

However, people sit because the places in which they spend their lives are structured around seats [30].

To compensate for the deleterious effects of sedentary habits in working places, some solutions such as ergonomic office and workstation design have emerged. They are intended to contribute to weight control/loss through additional energy expenditure, relief and prevent musculoskeletal pain (acute and chronic), and improve cardiometabolic health (e.g., adjustable sit-stand desktops). Workplace interventions that promote standing breaks and sit-stand adjustable workstations show improvements in health markers and increase work productivity, efficiency and collaboration among employees [27,31,32]. Although stand-up working at the computer doubles the energy expenditure over the 8 h workday and is a good alternative [33], the focus of healthy computer working has been put on preventing spine-related health problems derived from erroneous sitting postures. However, the questions are: Is there an ideal ergonomic position and sitting posture? Is energy expenditure the main health problem?

The Ideal Sitting Posture

The ideal sitting posture has been widely debated concerning back pain problems. A common belief is that spinal pain is caused by sitting, standing, or bending "incorrectly." Similarly, sitting up straight or looking for pelvis head alignment has been considered a healthy posture to prevent backache [34]. However, research has shown that there is no relationship between the shape and curves of the back with pain [35], neither movement screening for the prevention of pain in the workplace. Moreover, the complete consensus among experts concerning which is the best sitting posture does not exist because of disagreements on what constitutes a neutral spine posture and what is the best sitting posture. Even the chronic ideal posture for a long time can create as many problems as sitting all day [36], and also, repetitive movements can lead to injuries [37]. Despite the absence of strong evidence to support these common beliefs, health interventions and ergonomic assessments in offices are prescribed to get a "correct" posture and prevent pain.

The biomechanical definition of posture as a static configuration of the body in the space does not explain individual spinal variability (e.g., shapes, sizes), which is an adaptable structure capable of safely moving and loading in a variety of postures. From an enactive point of view, posture is embodied and dynamic: the action emerges from the interaction of emotions, intentions, motivations while the action is still ongoing [38]. Therefore, the change of posture has a wider dimension that includes personal constraints (e.g., muscular characteristics, height and proportions, psychological state) [39].

In general, posture studies highlight the importance of personalized management, as pain is influenced by numerous biopsychosocial factors. Claus et al. [40] proposed that any sustained sitting posture could result in fatigue, discomfort and pain, including the "bad" or the "good" postures if they persist uninterrupted for extended periods. This statement suggests that postural variability or regular movement can be beneficial in reducing maintained sitting posture risks. In this line, in the last decades, dynamic sitting approaches have been proposed, considering that subjects with back pain assume more static and sustained postures while sitting. Dynamic sitting is referred to the use of chairs or equipment that facilitates an increased trunk motion and spinal micro-movements, such as stability balls, chairs with a degree of motion or passive motion devices on the seat [41]. Comfortable postures vary between individuals, so it is useful to encourage people to move and explore different postures while sitting. The main problem is not the posture itself but the amount of time spent keeping it without changes. Hence, instead of looking for an ideal general posture, individuals and work companies should promote environments where movement and variety of postures are required and encouraged.

3. Current Recommendations for Maintaining Fitness Levels at Home during the COVID-19 Lockdown

Despite limited space or lack of special equipment, the WHO and the ACSM recommended 150 to 300 min of moderate-intensity or 75 to 150 min of vigorous-intensity PA per week during the COVID-19 lockdown [3]. The US Department of Health and Human Services, Office of Disease Prevention and Health Promotion, recently added a webpage entitled "Staying Active While Social Distancing", providing support for physical activity and guidance [29].

For desk-based workers, the recommendations proposed progressions from 2 h/day to 4 h/day of standing and light activity. To achieve this stage, they recommended regularly breaking up seated-based work with standing-based work, the use of sit-stand desks, or the taking of short active standing breaks. Interrupting prolonged sitting time has proved to have metabolic health benefits [42]. Regular interruptions of 3-min of light–intensity activities for 20 min of sedentary time have been suggested [43]. WHO exemplifies some practical home-based exercises and muscle-strengthening exercises available at their website (e.g., squats, planks, bridges, chair dips, etc.) to be performed for 10–15 repetitions up to five times with 1-min rest between sets to maintain PA during coronavirus mobility restrictions [3]. In addition, to increase exercise motivation, they propose Internet-delivered interventions that one can follow through electronic devices as a tool for everyone [44].

The use of ergometers and other technical devices has also been recommended to increase fitness levels and, particularly, total energy expenditure [45]. The purchase of ergometers, usually available in fitness centers where healthcare and exercise professionals usually refer their clients and patients, has become very popular during confinement, with a 170% rise in the purchase of sports equipment [46]. Despite their possibilities to provide vigorous-intensity activities, indirect measures of energy expenditure, and a precise quantification and regulation of resistance and cadence of movements, such devices present some limitations concerning similar activities performed under open-air conditions. In contrast, open-air activities provide a dynamical environment with exploration opportunities and movement variability [47]. Furthermore, there are other crucial health and fitness-related issues besides energy expenditure, often underestimated in the recommendations, that in interaction with exercise, have a relevant role on psychobiological states (i.e., nutrition, alcohol, smoking, stress or quality of life).

4. Alternatives to Current Recommendations

4.1. Improving Environmental Affordances

Affordance-responsiveness is a central feature of the everyday skillful activity of humans [48]. Affordances are possibilities for action provided by the environment, including possibilities for social interaction [49]. The notion of affordances are studied in different areas such as philosophy/phenomenology [50,51], sports/ecological psychology [52–54], affective science [55], and neuroscience [56]. However, affordances are not only possibilities of action; they invite behavior. For example, a room full of chairs affords sitting, an open space invites a conversation, and an extended hand invites a handshake. When a person encounters a meaningful affordance, a state of bodily action readiness occurs [57], and this is why chairs can "suck us in". If we radically change the affordances available in a certain environment, behavioral changes will occur [58]. Hence, the challenge lies in transforming both the physical and the social environment to reduce long-lasting immobility during home-based teleworking.

Architects and artists have manipulated work environments to create new affordances [59]. The newly created landscapes aim to develop behavioral changes through carefully selected and meticulously designed interventions in urban or rural areas that set the desired developments in motion. The multidisciplinary studio Rietveld Architecture-Art-Affordances (RAAAF) and visual artist Barbara Visser built an enactive art installation called The End of Sitting, a landscape without chairs that integrates many affordances for standing and increases bodily activity and wellbeing [59]. These designs lead to a range of affordances and offer users the freedom that characterizes everyday unreflective action [60]. Such actions emerge from the individual-environment interaction [10], and new affordances may create new movement habits during the working time [58]. For example, new landscapes without chairs, like the installations proposed by The End of

Sitting project, lead to more freedom of movement and new posture and body activity habits of participants during working periods associated with wellbeing [59].

4.2. Exergaming Approach

Virtual reality is an environment generated by computer technology, which allows user interaction and creates in the user the feeling of being immersed in it [61]. The interface environment provides full exploration and movement variability in people with disabilities [62]. Game properties (use of rewards, goals, feedback) and game engagement make virtual reality games use a great option for therapeutical purposes, motor skills learning, individualized learning and socialization [63]. Although games developed for rehabilitation purposes are expensive and hardly accessible, another type of game has been developed: exergames.

Exergaming is based on technology that tracks and projects body movements into an avatar on screen. Variety in exercise options provides a field for customizing games based on user's needs and motivations, such as walking, dancing, yoga, swimming, tennis, boxing or golf [44]. In current training interventions, prescribed exercises are executed with supervision in real time, but in exergaming at home, there is no real-time feedback or instruction. This sometimes requires a co-designing process between users/patients and professionals to adjust the exercise intervention according to the individual's response to exercise, progress and corresponding fitness and therapeutic needs [64].

Due to these advantages, exergames have been integrated into prevention and rehabilitation programs in different pathological conditions [65–69] turning out to be more motivating and engaging than conventional rehabilitation programs for children with obesity [70], healthy older adults [71,72], patients with Parkinson's disease [73], acquired brain injury [74], ataxia [75] and multiple sclerosis [76]. They have even reduced anxiety and stress levels during the isolation period in the COVID-19 pandemic [77]. The integration of exergames seems to have a positive effect on adherence, and thus, is potentially beneficial for the long-term effectiveness of rehabilitation programs [78]. To facilitate access to validated exergames for end-users and healthcare institutions, digital libraries can be found at https://openrehab.org (accessed on 31 December 2020) and https://seriousgames-portal.org (accessed on 31 December 2020).

Use of artificial intelligence to customize exercise prescriptions based on psychobiological factors could be a complementary tool to influence exercise behavior and movement habits. For example, the computerized exercise expert system (CEES) customizes exercise prescriptions based on personal questions administered to patients [79]. Performance evaluation of a recommending interface (PERI) offers the possibility to adjust and personalize exercise recommendations according to an evaluation performed from the deep learning neural network approach [80].

4.3. Mobile Applications with Fitness Purposes

Fitness products based on mobile applications have become popular due to the varied and safe home exercise options they offer. They do not depend on specific gym equipment (e.g., treadmill, bike) and may offer virtual free lessons through sports clubs and fitness instructors. Some of these apps also provide a virtual community and data tracking with the latest wearable technology, such as Apple watches, Garmin devices, or Fitbits smartwatches. Health metrics feedback transferred to healthcare professionals can supply valuable information to develop and readjust user's exercise characteristics. Nevertheless, relying on external devices for exercise monitoring may limit the development of somatic awareness, which is a necessary ingredient for developing adequate self-monitoring abilities and contribute to the user's autonomy and self-regulation.

5. New Perspectives and Practical Recommendations

Healthy home-based teleworking does not only consist of following the available general recommendations and guidelines of exercise prescription for healthy and clinical populations. There are huge differences in the daily physical activity of teleworkers in their previous experiences, injuries, diseases, preferred activities, etc. Accordingly, personalized healthy teleworking requires taking into account the following practical recommendations:

- *The acknowledgment of risks associated with prolonged immobility*

According to current guidelines, there is an extended belief that 30–40 min of moderate exercise per day is enough to keep fitness and healthy habits in adults. However, the effects of limited-time exercise bouts cannot compensate for the deleterious effects of lying down for the rest of the day. There is also a traditional assumption that there is an ideal sitting posture while working. Nevertheless, the immobility associated with keeping the same posture during long periods can induce, more than avoiding, health problems. Movement is necessary to coordinate organs [12], activate psychobiological functions and stimulate the body and the mind to keep the psycho-emotional and physical states that ensure job satisfaction, productivity, work–life balance, wellbeing and health.

- *Redefining health and fitness objectives*

It is recommended that healthcare professionals, exercise professionals and users/patients familiarize themselves with the recently redefined concepts of fitness and health [9,10], and reorient fitness objectives accordingly. Health states vary with personal and environmental constraints, and fitness objectives should adapt to it. Due to its multidimensional nature, fitness cannot be only developed through few conditional training dimensions (endurance and strength) [5,9,10]. Instead, it should focus on developing the functional diversity potential in a wide, multidimensional and personalized way. This means varying and adapting not only exercise challenges but also finding compensatory synergies through other abilities (e.g., intellectual, artistic) in order to evade and escape states of reduced possibilities.

- *Co-designing and co-adapting personalized exercise programs*

As there are no identical personal and environmental constraints and there is no universal way to develop fitness, healthcare professionals, exercise professionals and users are encouraged to collaborate in creating and developing personalized exercise programs. Based on flexible criteria, these programs pursue to promote adherence and adapting exercise periodization on a daily basis, according to the immediate constraints and affordances. Users' self-regulation of daily activity is the final aim of program interventions, and the role of professionals, instead of just prescribing exercise, is guiding users/patients from dependency to autonomy [5].

- *Development of user's somatic awareness*

Varied exercise and movement experiences may contribute to increase the functional diversity potential of users and develop their fitness [11]. Diverse and non-repetitive activities promote the creation of new synergies that may improve connectivity among organs and physiological systems. In turn, movement diversity provides rich body-mind information that enhances somatic sensitivity and awareness. The attention towards body signs may enhance self-monitoring abilities and develop further the somatic and informed awareness. It is then recommended avoiding or limiting the use of gadgets and applications for exercise and workout prescription and adjustments. For instance, it is preferable to take breaks or active pauses during work based on a subjective feeling of uneasiness or discomfort rather than on preprogrammed alarms.

- *Creation of personalized working environments limiting sitting and affording exercise and posture variations*

Home teleworkers are often able to organize their time and space according to individual needs. Exploration and discovery of personalized exercise and movement possibilities is a challenging process that requires users to be aware of the huge amount of available possibilities for changing postures and exercising. Exergaming contributes to diversifying home-based personalized exercise programs offering possibilities for exercising individually, in family, regulating intensity, and selecting motivating activities according to personal preferences.

The use of adjustable working stations allows changing posture, standing up or sitting, and provides movement possibilities and variations during the day. Employees indicate that some tasks can be completed standing or exercising at moderate intensities, e.g., checking emails and making phone calls. However, other tasks such as reading or writing, involving greater concentration, are better performed during sitting. According to some authors, the commitment to standing is influenced by the perception of improved productivity and experience of health benefits [81]. Enabling floor to work provides further movement possibilities and openness to new affordances. This means more readiness to engage with relevant opportunities for action in a concrete situation [58]. The exploration of new movement possibilities (e.g., local, global, micro-movements, different types of contractions, different muscle group activation, changing postures, making active pauses, stretching) can also be encouraged through personal challenges.

- *Complementary proposals*

Sitting less and moving more are recommended to change the intensity of some daily activities (e.g., reducing car use, running instead of walking, dancing, walking during phone calls, shopping using bikes). Ergometers can also be used while watching videos, chatting, or listening to audio. It is important to prioritize outdoor activity whenever possible. Research from a variety of scientific fields suggests that physical activity in nature enhances health-related quality of life and long-term adherence to physical activity [82].

6. Limitations and Future Lines of Research

Proposing exercise criteria and workout self-regulation based on subjective monitoring and somatic awareness, instead of on prescribed exercise recipes, may allow an adequate contextualization and personalization of physical activity during teleworking, but may increase potential risks associated with exercise (e.g., injuries, overtraining). However, there is a lack of research confirming the prevalence of risks related to self-prescribed or unsupervised exercise [83], in contrast to self-prescribed medication [84]. To avoid potential risks, it is recommended developing somatic awareness at an early age, and promote it during the intervention process. It is relevant to highlight here that an excessive or obsessive focus on body awareness may intensify the symptomatology of users predisposed to suffering hypochondria. In this sense, more research related to the development of somatic awareness and, in particular, to the less used concept of informed awareness [84]. The term informed awareness refers to the information about oneself (e.g., proprioception, interoception) in relation to the environmental information.

It is worth pointing out that systematic, repetitive exercise, as proposed by current guideline recommendations, is one more option among all exercise possibilities that can be offered. It may be as well contextually valid, especially when user's preferences are addressed to it. As health and fitness have a subjective dimension, it seems recommendable to respect users' preferences and develop progressively their understanding related to the advantages derived from varied exercise modalities and challenges.

Finally, although computer technologies and mobile applications may suppose useful and easy solutions for exercise prescription and fitness evaluation, it is suitable that users do not simply rely on technical devices for selecting exercise options and assessing their fitness and health status. The continuous use of external devices replacing important human abilities related to survival, such as somatic and informed awareness, can be detrimental at long term [85]. In addition, the development of self-responsibility towards own fitness and health is of key importance [84].

7. Conclusions

Home teleworking, associated with sedentary behavior, may suppose a threat to health. Recommended standardized exercise programs, based on the one-size-fits-all approach, maybe insufficient and even misleading to promote fitness and health. Twenty to thirty min of moderate exercise cannot compensate for the deleterious effects of sitting the rest of the day, as might be misinterpreted from current guidelines. A personalized exercise counseling should place particular attention on (a) educating professionals and users on the redefined concepts and objectives of health and fitness, (b) design interventions focused on developing the functional diversity potential of users, (c) promote the creation of functional compensatory synergies in multiple dimensions to evade user's states of reduced possibilities, (d) co-design and co-adapt exercise interventions together with users, (e) contribute to develop user's somatic awareness and workout self-regulation competencies, (f) creating adequate environmental contexts affording movement variation possibilities and motivating exertion, instead of focusing on ideal and unique solutions (e.g., the ideal posture).

A better understanding of health and fitness objectives by professionals and users is crucial to develop adequate person-centered exercise solutions and counteract sedentary tendencies during teleworking. The active participation of users in the co-design and co-adaptation of personalized exercise programs is of key importance for exercise adherence and health prevention. Computer technologies may provide support to the co-designed programs but cannot replace users' decisions and users' monitoring abilities based on somatic awareness. It is crucial that healthcare and exercise professionals bear in mind that one of the main aims of the intervention process is developing user's autonomy and self-responsibility towards one's own fitness and health. Empirical research is warranted to study the effects of cooperative and self-prescribed exercise on producing safe and effective interventions regulated by somatic awareness.

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3. Hipòtesi i objectius

3.1. Hipòtesi

- Les intervencions d'exercici basades en els criteris de la Fisiologia de Xarxes tindran efectes més positius en l'estat de forma, la salut mental i el benestar en adults sans en comparació a les recomanacions de l'OMS.

3.2. Objectiu general

Revisar i actualitzar les directrius d'exercici per a la salut de l'OMS, i establir criteris d'intervenció/entrenament personalitzats basats en la perspectiva de la Fisiologia de Xarxes.

3.3. Objectius específics

1. Revisar i actualitzar els supòsits teòrics i metodològics de les evidències científiques que donen suport a l'actual prescripció d'exercici per la salut. – *1. Network Physiology of Exercise: vision and perspectives*
2. Aplicar els principis del nou marc programàtic de la Fisiologia de Xarxes per personalitzar les recomanacions d'exercici per a la salut i, adaptant-les al context del teletreball. – *2. Healthy teleworking: towards personalised exericse recommendations.*
3. Comparar els efectes d'intervencions d'exercici basades, respectivament, en recomanacions de la OMS i els principis de la Fisiologia de Xarxes de l'exercici sobre l'estat de forma o fitness, la salut mental i el benestar en adults sans. Article original: – *3. Prescribing or co-designing exercise in healthy adults? Effects on mental health and interoceptive awareness.*

4. Material i mètode

4.1. Participants

Un total de vint adults sans (10 homes i 10 dones) amb edats compreses entre els 40 i els 50 anys, amb un nivell socioeconòmic mitjà, nivell d'educació universitari i sense participació en activitat física regular, es van oferir com a voluntaris per participar en aquest estudi. Tenint en compte una potencia de la mostra del 0.8, un nivell de significança de $p < 0{,}05$ i una mida d'efecte mitjà (0,5), la mida total de la mostra calculada utilitzant el programari G * Power v3.1.9.7 va ser de 12 participants. Per compensar la possible pèrdua de seguiment, la mostra proposada va ser de 20 participants.

Els criteris d'exclusió van ser els següents: a) informar de qualsevol contraindicació i lesió que impedeixi fer exercici físic; b) les prohibicions d'intervencions de proves físiques; i c) dependents d'un marcapassos, embarassades, persones amb un IMC superior a 30 kg/m2 o amb estenosi coneguda de l'artèria caròtida o femoral.

Després de ser informats sobre el procediment de l'estudi i signar un consentiment informat, els participants van realitzar una prova d'exercici càrdiorrespiratoria i van respondre a dos qüestionaris (MAIA i DASS) a través de formularis de Google. Totes les respostes es van codificar per garantir la privadesa i l'anonimat de les dades. Posteriorment, van ser dividits aleatòriament en dos grups de 10 membres cadascun que van seguir dos programes d'exercici diferents durant 9 setmanes: (a) una intervenció d'exercici co-dissenyada (grup CoD), i (b) un programa d'exercici estandarditzat basat en les recomanacions de l'OMS (grup OMS). Ambdós grups tenien un estat físic i puntuacions de qüestionaris similars. Els participants van ser assignats aleatòriament a 7 entrenadors personals (graduats en Ciències de l'Esport) amb un mínim de 3 anys d'experiència professional i entrenats específicament durant 2 setmanes per desenvolupar els dos programes d'intervenció. Cada entrenador va supervisar virtualment 2-3 participants. Van supervisar l'entrenament en línia i van interactuar amb els participants dues vegades a la setmana. També van mantenir reunions amb el coordinador de la recerca per fer un seguiment de la intervenció setmanalment. El projecte de recerca va ser aprovat pel Comité d'Ètica d'Investigacions Clíniques de l'Administració Esportiva de Catalunya (ref. 07/2015/CEICEGC).

Un total de 7 participants (2 al grup CoD i 5 al grup OMS) no van completar el programa d'intervenció.

4.2. Procediment

4.2.1. Intervenció co-disenyada d'exercici

Tenia dos objectius principals: (a) promoure la salut mitjançant el co-disseny d'activitats significatives i personalment motivadores, i (b) desenvolupar l'autonomia dels participants, la seva responsabilitat personal i la seva consciència interoceptiva. Els participants van proposar activitats que els agradava fer o que els agradaria provar. Els entrenadors personals també van suggerir activitats que podrien ser significatives i motivadores per al participant, no només aquelles basades en moviments cíclics o repetitius. Per exemple: jugar amb els seus fills, fer activitats a l'aire lliure, jugar a videojocs d'exercici, fer estiraments a l'oficina i utilitzar la bicicleta per desplaçar-se, entre altres.

4.2.2. Programa d'exercici estàndard basats en les recomanacions de l'OMS

Consistia en exercicis de ciclisme o córrer, realitzats 5 dies per setmana a baixa intensitat o 3 dies per setmana a intensitat vigorosa, amb una durada mínima de 25-30 minuts per sessió, segons les directrius de l'OMS (17). El entrenament de força consistia en un circuit d'alta intensitat de 12 estacions (47) realitzat dues vegades per setmana segons les directrius de l'ACSM (5). Tots els exercicis es podien fer amb el propi pes corporal en gairebé qualsevol entorn (per exemple, a casa, a l'oficina, a l'habitació de l'hotel, etc.). Els exercicis es realitzaven durant 30 segons, amb 10 segons de temps de transició entre series. El temps total per a tota la sessió de circuit era d'aproximadament 7 minuts. El circuit es podia repetir 2-3 vegades. La intensitat i el volum de la càrrega es regulaven setmanalment per mantenir una percepció de l'esforç (escala Borg CR 10) de 3-5 en totes les sessions (consulteu la taula III).

Taula III. Comparació de les característiques d'un programa d'exercici basat en les recomanacions de l'OMS i de les característiques d'una intervenció co-dissenyada.

Tipus de programa	Programa d'exercicis de l'OMS (OMS)	Intervenció co-dissenyada (CoD)
Basat en	Recomanacions de l'OMS i ACSM	Co-disseny
Exercici	Repetitiu, amb sèries i repeticions	Variat
Tipus d'activitat	Exercicis aeròbics (córrer, bicicleta) i de força	Exercicis basats en les preferències individuals
Freqüència	Exercici aeròbic: 5 d/set Exercici de força: 2 d/set	5 d/ set
Intensitat	Exercici aeròbic: RPE (CR 10): 3-5 Exercici de força: RPE (CR): 8	RPE (CR 10): 3-5
Durada	300 min / set	300 min / set

Font: Elaboració pròpia.

4.3. Mesures

Es va realitzar una prova d'exercici càrdiorrespiratoria i dos qüestionaris (consulteu a continuació) abans i després de la intervenció, i es va realitzar una entrevista personal al final de la intervenció. La prova d'exercici càrdiorrespiratoria va ser supervisada pel personal mèdic que va confirmar l'estat de salut dels participants. Els qüestionaris es van respondre en línia utilitzant formularis de Google, i un investigador extern va dur a terme les entrevistes personals per videoconferència.

4.3.1. Prova cardiorespiratòria

Es va realitzar una prova incremental de ciclisme (Excalibur, Lode, Groningen, Països Baixos) començant a 50 W i augmentant la càrrega en 30 W/min fins a assolir una percepció subjectiva de l'esforç (escala CR-10) de "molt dur" (RPE 8). Els participants respiraven a través d'una vàlvula (Hans Rudolph, 2700, Kansas City, MO, Estats Units), i l'intercanvi gasós respiratori es va determinar utilitzant un sistema automatitzat de circuit obert (Metasys, Brainware, La Valette, França). El contingut d'oxigen i CO_2 i la taxa de flux d'aire es van enregistrar batejant per batejada. Un electrocardiograma (ECG) es va monitoritzar de manera contínua (DMS Systems, transmissor i receptor d'ECG Bluetooth sense fils DMS-BTT, programari Versió 4.0 de DMS, Beijing, Xina). La prova es va realitzar en un laboratori ben ventilat; la temperatura de la sala era de 23 C i la humitat relativa del 48%, amb variacions de no més de 1C en la temperatura i del 10% en la humitat relativa. Les proves es van realitzar com a mínim 3 h després d'un àpat lleuger, i als participants se'ls va instruir que no realitzessin activitat física vigorosa durant les 72 h abans de les proves.

4.3.2. Questionnaris

- *Escala de Depressió, Ansietat i Estrès/Depression, Anxiety and Stress (DASS-21)*

La versió en espanyol del qüestionari DASS-21 (48) va avaluar els estats emocionals negatius auto-informats durant la darrera setmana. Aquest qüestionari conté 21 afirmacions valorades en una escala Likert de quatre categories (des de 0 = "no s'aplica gens a mi" fins a 3 = "s'aplica molt a mi la major part del temps"), distribuïdes en tres subescales (amb set ítems cadascuna): Depressió, Ansietat i Estrès (49,50). La escala de depressió avalua la disfòria, la desesperança, la devaluació de la vida, la manca d'interès / implicació i la inèrcia (per exemple, no podia entusiasmar-me per res). La escala d'ansietat avalua el nivell d'activació autonòmic, els efectes sobre el múscul esquelètic, l'ansietat situacional i l'experiència subjectiva de l'afecte ansiós (per exemple, era conscient de l'acció del meu cor en absència d'esforç físic). La escala d'estrès és sensible als nivells d'activació crònic no específic. Avalua la dificultat per relaxar-se, la activació nerviosa, i ser fàcilment irritat / agitat, irritable / sobreactiva i impacient (per exemple, era intolerant amb qualsevol cosa que em distragués de fer el que estava fent).

Les puntuacions per a la depressió, l'ansietat i l'estrès es calculen sumant les puntuacions dels ítems corresponents. Els valors de l'alfa de Cronbach i la fiabilitat test-retest indiquen una bona consistència interna de la versió en espanyol del DASS-21 (48).

- *Avaluació Multidimensional de la Consciència Interoceptiva/ Multidimensional Assessment of Interoceptive Awareness (MAIA)*

Es va administrar la versió en castellà del qüestionari *Multidimensional Assessment of Interoceptive Awareness* (MAIA) (51). Es tracta d'un instrument desenvolupat per Mehling et al. (52) per mesurar vuit dimensions de la consciència corporal interoceptiva. La escala de **percepció** avalua la consciència de les sensacions corporals incòmodes, còmodes o neutres (per exemple, "quan estic tens, noto on es localitza la tensió en el meu cos"). La escala de **no distracció** avalua la tendència a no recórrer a la distracció per fer front al malestar (per exemple, "quan sento dolor o malestar, intento superar-ho"). La escala de **no preocupació** avalua la tendència a no experimentar angoixa emocional amb el malestar físic (per exemple, "puc notar una sensació corporal desagradable sense preocupar-me'n"). La escala de **regulació de l'atenció** avalua la capacitat de mantenir i controlar l'atenció a les sensacions corporals (per exemple, "puc mantenir la consciència de les meves sensacions corporals internes fins i tot quan hi ha molt soroll al meu voltant"). La escala de **consciència emocional** avalua la capacitat d'atribuir sensacions físiques específiques a manifestacions fisiològiques de les emocions (per exemple, "quan alguna cosa va malament a la meva vida, ho puc sentir en el meu cos"). La escala d'**autoregulació** avalua la capacitat de regular la angoixa mitjançant l'atenció a les sensacions corporals (per exemple, "puc utilitzar la meva respiració per reduir la tensió corporal"). La escala **d'escolta de senyals corporals** avalua la tendència a escoltar activament el cos per obtenir informació (per exemple, "escolto el meu cos perquè em doni informació sobre què fer"). La escala de **confiança** avalua l'experiència del propi cos percebuda com un lloc segur i fiable (per exemple, “sento que el meu cos és un lloc segur”). Presenta 32 ítems en una escala Likert, amb sis nivells de resposta ordinal codificats de 0 (mai) a 5 (sempre), generant una puntuació total en una escala entre 0 a 160 punts. La versió en castellà mostra indicadors adequats de validesa de constructe i fiabilitat, amb un alfa de Cronbach de 0,90 per a l’escala total i valors entre 0,40 i 0,86 per a les diferents subescales (51).

4.3.3. Entrevistes

Els participants van ser convidats a una entrevista semiestructurada de 30 minuts realitzada per un investigador extern a la intervenció per evitar el biaix. L’entrevista semiestructurada guia els punts crítics de la intervenció alhora que permet que apareguin nous temes o qüestions. La fiabilitat de les entrevistes es va garantir mitjançant el mateix entrevistador, el mateix disseny de les preguntes, la mateixa durada d’interrogatori i el mateix període per a totes les entrevistes. Les entrevistes es van enregistrar en vídeo i es van transcriure textualment. Dos investigadors experts en anàlisi qualitatiu i cinc professionals de Ciències de l’Esport van validar la guia de l’entrevista previ a l’estudi. Aquesta consistia en preguntes sobre: experiències prèvies, raons per involucrar-se en el programa d’exercici, beneficis o reptes percebuts per participar, i el rol de l’entrenador personal (per exemple, “Creus que la figura de l'entrenador personal és essencial per continuar amb el nivell d’activitat física assolit?”), raons per abandonar la pràctica, el que han après (per exemple, “Has adquirit recursos per adaptar l’exercici a qualsevol situació i circumstància personal?”) i la disposició per implementar canvis en l'estil de vida més enllà del programa (per exemple, “Has descobert alguna activitat física per incorporar en els teus hàbits?”).

4.4. Anàlisi de dades

4.4.1. Proves fisiològiques

La relació entre la càrrega de treball corresponent al RPE 8 i el consum d’oxigen relatiu al pes corporal (W/VO2); la relació entre la càrrega corresponent al RPE 8 i la freqüència cardíaca (W/FC) es van comparar abans i després de la intervenció utilitzant el test de Wilcoxon per a mostres aparellades i el t-test per a mostres independents.

4.4.2. Qüestionaris

Es van calcular les mitjanes amb intervals de confiança del 95%, les medianes, les desviacions estàndard i els rangs interquartils per avaluar la ubicació i la dispersió de les puntuacions obtingudes en els qüestionaris del DASS-21 i del MAIA. La simetria i la curtosi es van utilitzar per determinar la forma i la normalitat de la distribució de les puntuacions. Les diferències intra-grup pre-post es van avaluar utilitzant proves t aparellades i les diferències inter-grup a través de proves t per a mostres independents. Les magnituds de l'efecte es van calcular mitjançant la d de Cohen. Totes les anàlisis estadístiques quantitatives es van realitzar utilitzant SPSS (versió 25, IBM Corp).

4.4.3. Entrevistes

Totes les transcripcions de les entrevistes es van comparar amb les gravacions en vídeo per garantir l'exactitud. Es van assignar codis d'identificació [OMS, CoD o NC (no completa la intervenció), amb números consecutius (per exemple, CoD4)]. Es va utilitzar l'anàlisi de contingut per identificar els temes emergents fins que es va assolir la saturació (53). Dos investigadors van revisar de manera independent la transcripció per identificar codis utilitzant el programari NVIVO (versió 2, QRS International Pty Ltd). Després, van discutir els resultats i es van presentar els temes i subtemes proposats derivats de les dades a l'equip d'investigació fins que es va arribar a un consens final.

5. Resultats

S'actualitzen els supòsits teòrics i metodològics de les evidències científiques que donen fonament a les prescripcions d'exercici per a la salut de l'OMS provinents de la Fisiologia de l'Exercici amb els de la Fisiologia de Xarxes de l'Exercici (veure taula IV). Aquesta última suposa una nova àrea en Ciències de l'Exercici i de l'Esport que integra les lleis bàsiques d'interaccions dels SCA i principis de coordinació entre diversos sistemes fisiològics a través d'escales espacio-temporals.

Taula IV. Contrast entre supòsits teòrics i metodològics de la Fisiologia de l'Exercici i la Fisiologia de Xarxes de l'Exercici.

Supòsits teòrics	Fisiologia de l'Exercici	Fisiologia de Xarxes de l'Exercici
Sistemes	Dominats pels seus components	Dominat per les interaccions entre components
Teoria	Reduccionisme, Cibernètica clàssica	Ciència de xarxes, Teoria de sistemes dinàmics
Control	Sistema nerviós central com a principal regulador/programador	Sistema regulat paramètricament
Mecanismes	Homeostàtic	Homeodinàmic
Trets metodològics		
Variables	Variables aïllades	Variables col·lectives en xarxa
Mesures	Valors mitjans i màxims de variables	Dinàmiques de connectivitat/ sinergies/coordinació
Adquisició de dades	Dades agrupades	Sèries temporals intraindividuals
Anàlisi	Generalització de població a individual	Generalització individual a població
Relacions	Inferències estadístiques de baix a dalt (des de nivells micro fins a macro).	Interaccions dinàmiques de baix a dalt i de dalt a baix (causalitat circular).

Font: Elaboració pròpia, consulteu Balagué i col, (55).

Els principis de la Fisiologia de Xarxes es van aplicar al context del teletreball, establint uns criteris d'intervenció personalitzats que s'adapten a les necessitats i contextos individuals més enllà de l'estat de forma. A través de revelar alguns dels mites de l'exercici, com la postura ideal i l'ús de la tecnologia per prescriure i re definir els rols de professionals i usuaris/àries. Es suggereix implementar una estratègia de co-disseny en els programes d'exercici, involucrant tant a professionals com a usuaris/àries en el disseny i la implementació dels programes d'exercici. De manera que els pacients siguin partícips del seu propi procés de salut i per garantir una millor adaptació i adherència.

La comparació dels efectes d'intervencions d'exercici basades en les recomanacions de l'OMS i en els principis de la Fisiologia de Xarxes, revelen diferències significatives en l'estat de forma o fitness, la salut mental i el benestar en adults sans. A continuació es presenten els resultats de l'estudi original d'aquesta tesi.

5.1. Proves fisiològiques

No es van trobar diferències en W/VO2 i W/FC abans i després de la intervenció en ambdós grups (OMS i CoD), ni entre grups.

5.2. Qüestionaris

Tots els participants van respondre als qüestionaris DASS-21 i MAIA, però només 13 d'ells van completar la intervenció (CoD = 8, OMS = 5).

- *Escala de Depressió, Ansietat i Estrès/Depression, Anxiety and Stress (DASS-21)*

Els nivells de depressió, ansietat i estrès en el qüestionari DASS es presenten a la taula V. Després de la intervenció, el grup CoD va millorar les seves puntuacions en les tres dimensions del qüestionari DASS-21: depressió [$t(7) = 7{,}907$, $p < 0{,}0001$], ansietat ($t = 27{,}032$, $p < 0{,}0001$) i estrès ($t = 8{,}973$, $p < 0{,}0001$). Tanmateix, no es van detectar diferències en el grup OMS. Les diferències intergrup van mostrar nivells d'ansietat més elevats (W = 36,000, Z = –3,038, p = 0,002, d = 0,84) i estrès (W = 39,500, Z = –2,449, p = 0,011, d = 0,68) en el grup OMS comparat amb el grup CoD.

Taula V. Descripcions dels ítems del qüestionari DASS

	Grup	N	Mitjana	SD	Variança	Simetria	SE	Curtosi	SE
PRE_Depressió	CoD	8	12.250	4.46	19.93	1.0261	0.752	-0.234	1.48
	OMS	5	8.400	7.80	60.80	1.9861	0.913	3.948	2.00
POST_Depressió	CoD	8	1.500	1.41	2.00	0.4041	0.752	-0.229	1.48
	OMS	5	6.000	4.24	18.00	-0.5238	0.913	-0.963	2.00
PRE_Ansietat	CoD	8	13.000	1.51	2.29	-1.3229	0.752	0.875	1.48
	OMS	5	9.200	5.93	35.20	-0.8849	0.913	1.449	2.00
POST_Ansietat	CoD	8	0.750	1.04	1.07	0.6441	0.752	-2.240	1.48
	OMS	5	10.000	2.45	6.00	1.3608	0.913	2.000	2.00
PRE_Estrès	CoD	8	17.750	4.83	23.36	-0.5353	0.752	-0.744	1.48
	OMS	5	8.800	5.76	33.20	-0.0376	0.913	-1.804	2.00
POST_Estrès	CoD	8	4.000	3.02	9.14	0.3307	0.752	-1.488	1.48
	OMS	5	14.400	9.42	88.80	1.4646	0.913	2.443	2.00

Font: Elaboració pròpia.

- *Avaluació Multidimensional de la Consciència Interoceptiva/ Multidimensional Assessment of Interoceptive Awareness (MAIA)*

Les descripcions del qüestionari MAIA es presenten a la taula VI. Després de la intervenció, el grup CoD va millorar en 7 de les 8 escales del qüestionari MAIA: percepció [t(7) = –1,276, p < 0,0001], no-distraure [t(7) = –4,492, p = 0,003], regulació de l'atenció [t(7) = –26,839, p < 0,0001], consciència emocional [t(7) = –13,642, p < 0,0001], autoregulació [t(7) = –13,316, p < 0,0001], escolta corporal [t(7) = –7,848, p < 0,0001], confiança [t(7) = –10,991, p < 0,0001] excepte per no preocupar [t(7) = – 1,276, p = 0,243]. En el grup OMS, es van detectar diferències només en 3 escales, autoregulació [t(4) =

4,376, p = 0,012], escolta corporal [t(4) = –6,144, p = 0,004] i confiança [t(4) = –6,364, p = 0,003].

Taula VI. Descripcions dels ítems del qüestionari MAIA

	Grup	N	Mitjana	SD	Variança	Simetria	SE	Curtosi	SE
PRE_Percepció	CoD	8	1.91	0.7063	0.4989	-0.7578	0.752	2.4997	1.48
	OMS	5	2.10	0.5477	0.3000	1.5310	0.913	1.7448	2.00
POST_Percepció	CoD	8	4.25	0.7440	0.5536	-1.2140	0.752	1.5595	1.48
	OMS	5	4.55	0.4472	0.2000	-0.0524	0.913	-2.3242	2.00
PRE_No-distraure	CoD	8	2.92	0.3897	0.1518	1.3533	0.752	0.6000	1.48
	OMS	5	2.80	0.1807	0.0327	0.6086	0.913	-3.3333	2.00
POST_No-distraure	CoD	8	4.08	0.6357	0.4041	-1.7759	0.752	4.0011	1.48
	OMS	5	4.27	0.4349	0.1891	-0.5215	0.913	-1.5244	2.00
PRE_ No preocupar	CoD	8	2.08	1.3060	1.7056	0.3178	0.752	-0.1760	1.48
	OMS	5	2.20	1.3431	1.8039	1.0194	0.913	2.0429	2.00
POST_No preocupar	CoD	8	2.59	0.3908	0.1527	-0.8853	0.752	-0.4606	1.48
	OMS	5	2.73	0.0158	2.5004	1.4014	0.913	-1.2000	2.00
PRE_ Regulació atenció	CoD	8	2.10	0.5165	0.2667	0.4576	0.752	-0.4061	1.48
	OMS	5	2.08	0.6106	0.3728	-1.0217	0.913	0.6871	2.00
POST_Regulació atenció	CoD	8	4.08	0.5560	0.3091	-0.3548	0.752	-0.6512	1.48
	OMS	5	3.37	0.9125	0.8326	0.1683	0.913	-1.1433	2.00
PRE_ Consciència emocional	CoD	8	2.50	0.6928	0.4800	0.2887	0.752	-0.9250	1.48
	OMS	5	3.36	0.6542	0.4280	-2.1342	0.913	4.6790	2.00
POST_ Consciència emocional	CoD	8	4.42	0.5701	0.3250	-0.3154	0.752	-1.7276	1.48
	OMS	5	4.00	1.1489	1.3200	-1.0550	0.913	0.9669	2.00
PRE_Autoregulació	CoD	8	2.16	0.6400	0.4096	0.2161	0.752	-0.1049	1.48
	OMS	5	2.60	1.3062	1.7063	0.5861	0.913	-0.3385	2.00
POST_Autoregulació	CoD	8	4.38	0.6124	0.3750	-0.7776	0.752	-0.0571	1.48
	OMS	5	3.70	1.0216	1.0437	-0.3473	0.913	0.4149	2.00
PRE_Escolta corporal	CoD	8	2.04	1.3499	1.8222	-0.0175	0.752	-0.9724	1.48
	OMS	5	1.73	0.9269	0.8591	0.2371	0.913	-0.8817	2.00

POST_Escolta	CoD	8	4.12	0.6657	0.4431	-0.1099	0.752	0.0280	1.48
corporal	OMS	5	3.67	1.1058	1.2228	-0.6821	0.913	1.1194	2.00
PRE_Confiança	CoD	8	2.58	0.6117	0.3741	0.6851	0.752	-0.4693	1.48
	OMS	5	2.73	1.3650	1.8631	1.5223	0.913	2.5324	2.00
POST_Confiança	CoD	8	4.42	0.4961	0.2461	0.4799	0.752	-2.2481	1.48
	OMS	5	4.00	1.0277	1.0561	-1.2840	0.913	2.0199	2.00

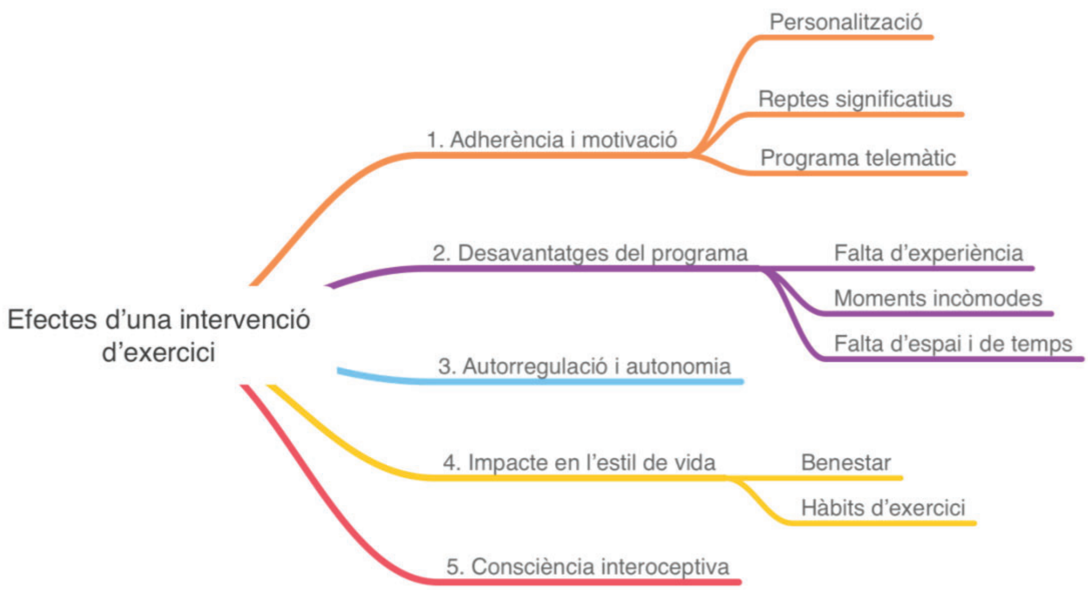
Font: Elaboració pròpia.

Després de la intervenció, es van observar diferències entre grups en la percepció (W = 20,500, Z = –2,140, p = 0,030, d = 0,59), no-distracció (W = 18,500, Z = –2,442, p = 0,011, d = 0,68), regulació de l'atenció (W = 16,000, Z = –2,789, p = 0,003, d = 0,77), autoregulació (W = 15,000, Z = –2,956, p = 0,002, d = 0,81), escolta de senyals corporals (W = 15,000, Z = –2,952, p = 0,002, d = 0,82) i confiança (W = 15,000, Z = –3,029, p = 0,002, d = 0,84) a favor del grup CoD.

5.3. Entrevistes

Tots els participants van ser entrevistats, inclosos aquells que no van completar la intervenció. L'anàlisi de contingut va confirmar la saturació de dades a n = 20 i va revelar cinc temes basats en les preguntes de les entrevistes (vegeu la figura 1).

Figura I. Temes i subtemes desenvolupats a partir de les experiències dels participants



5.3.1. Tema 1: Adherència i motivacions durant el programa

Ambdós grups van coincidir en què ser supervisats per l'entrenador personal i rebre una retroalimentació constant va facilitar la seva participació. Destaquen la personalització del co-disseny com a motivadora que els hi va a ajudar a continuar. També van apreciar els reptes significatius i innovadors; "No saber quins reptes l'entrenador personal anava a presentar-me la setmana següent em mantenia curiós i motivat" (CoD8). Un altre benefici àmpliament informat va ser un programa d'exercicis portat de manera telemàtica; "No era necessari anar a un lloc específic; podia fer l'exercici a casa durant el meu temps lliure" (OMS2).

5.3.2. Tema 2: Desavantatges del programa

Els participants del grup de l'OMS van reportar nivells més elevats d'ansietat i estrès a causa de la seva manca d'experiència en l'exercici; "Al principi, era estressant perquè no estic acostumat i no em sentia en forma" (NC5). Com que principalment feien exercici a casa o a la feina, se sentien avergonyits quan eren observats pels membres de les seves famílies o companys de feina; "Anava al lavabo a fer alguns exercicis perquè els meus companys de feina no em veiessin" (CoD6). "Durant les vacances de Nadal, tenia la meva família a casa i em preocupava el que podrien dir al veure'm practicar exercici" (NC3). L'horari de feina dificultava la participació, i la manca de temps va ser el problema més destacat en ambdós grups; "Tinc poc temps lliure i em resulta difícil combinar l'exercici amb la vida familiar. L'activitat física no és una prioritat per a mi" (OMS4). Els participants que no van completar la intervenció van informar de la manca d'espai o temps per fer exercici; "Inicialment em sentia molt emocionat, però després va ser difícil conviure i gaudir-ne a causa de l'horari de la feina" (NC4). Van abandonar l'estudi per la manca de flexibilitat horària i incompatibilitat del programa; "Ha estat impossible per a mi combinar-ho amb els assumptes laborals i familiars" (NC6). La majoria dels participants del grup CoD, que també van tenir la dificultat del temps, van aconseguir adaptar-s'hi incorporant l'activitat física a la seva vida diària de manera autònoma; "El primer dia, només vaig caminar durant 30 minuts, i a mesura que passaven les setmanes, vaig augmentar el temps perquè em sentia millor cada dia" (CoD6).

5.3.3. Tema 3: Autoregulació i autonomia

Els participants del grup CoD van adaptar l'exercici a les seves limitacions personals i ambientals i van aprendre a autoregular la càrrega de treball. "Durant les vacances, no estava acostumat a fer exercici, però aquesta vegada vaig poder fer-ho perquè sabia les activitats que podia fer" (CoD2) i "Poder gestionar la intensitat i la durada de l'activitat em va ajudar a fer molt més del que pensava al principi" (CoD2). No percebien la figura de l'entrenador com a essencial a causa de l'autonomia apresa; "Amb el temps vaig poder decidir diàriament quines activitats eren adequades i quines no" (CoD1). Al grup de l'OMS no es van reportar el desenvolupament de les capacitats d'autoregulació i autonomia en l'exercici; "Encara que estigués estressat per la feina, vaig fer les sèries i repeticions de l'entrenament de força que havia de fer" (OMS5). Els participants que no van completar la intervenció van trobar difícil implicar-se i adaptar el programa d'exercici a les seves necessitats i consideraven que assumien massa responsabilitat; "És impossible per a mi autoregular la intensitat i el tipus d'activitat perquè sempre estic tan cansat que mai faria res" (NC2).

5.3.4. Tema 4: Impacte en l'estil de vida

El grup CoD va augmentar la consciència de si mateix i el benestar personal: "Noto que quan camino, em canso menys, i també noto menys arrítmies des de l'inici del programa"(CoD6). Molts van parlar dels seus plans per continuar fent exercici a causa del seu benestar i confiança; "Em sento bé amb mi mateix i amb el meu cos" (CoD5). A més, alguns d'ells han contractat un entrenador personal per continuar fent exercici; "He decidit continuar amb un entrenador personal per provar noves activitats diferents que sempre he volgut provar" (CoD7). Altres participants van expressar haver adquirit consciència corporal "Ara soc més conscient de l'activitat física que faig en la meva vida diària, i de com em sento durant i després de fer-la" (CoD2). "Encara estic fent exercici, incorporant els principis que vaig aprendre amb l'entrenador" (CoD3). El grup de l'OMS també va planejar canviar els seus hàbits apuntant-se a un gimnàs per poder trobar el material requerit; "He decidit unir-me a un gimnàs per tenir accés a més material; és més fàcil per a mi seguir rutines d'exercici" (OMS5). D'acord amb els resultats dels qüestionaris; "He descobert que l'exercici ajuda a reduir els meus nivells d'ansietat i estrès" (OMS3).

5.3.5. Tema 5: Consciència interoceptiva

Mentre que el grup de l'OMS va relacionar la intervenció amb la seva forma física, el grup CoD la va relacionar amb múltiples dimensions i amb un estat de benestar més general: "Per a mi, la salut és més que un estat físic. Es tracta de sentir-se còmode amb un mateix i de saber com escoltar el cos per adaptar-se a diferents contextos" (CoD7). Ambdós grups van afirmar que mai se'ls havia preguntat sobre l'estat del seu cos i les sensacions envers l'exercici. No obstant això, només el grup CoD va mencionar que havien millorat la seva consciència interoceptiva; "Puc reconèixer estats inflamatoris en el meu cos basats en l'estrès, el que he menjat o el que he dormit" (CoD5), "Quan estic nerviosa, no puc confiar en les senyals del meu cos" (OMS2). En general, 13 dels 20 participants van estar satisfets amb el programa d'exercici, però només els participants del grup CoD recomanarien el programa a altres persones; "Gràcies al diàleg constant amb l'entrenador personal i a provar diferents propostes, he descobert els tipus d'activitats que em funcionen. De fet, les he incorporat com un hàbit diari" (CoD3); mentre que altres haurien preferit un seguiment diari i una planificació exhaustiva de l'entrenament; "Prefereixo tenir una rutina d'exercici programada amb instruccions tècniques" (CoD7).

6. Discussió

La discussió s'estructura en dos apartats: a) actualització i personalització de les recomanacions d'exercici per a la salut b) limitacions i reptes de futur.

6.1. Actualització i personalització de les recomanacions d'exercici per a la salut

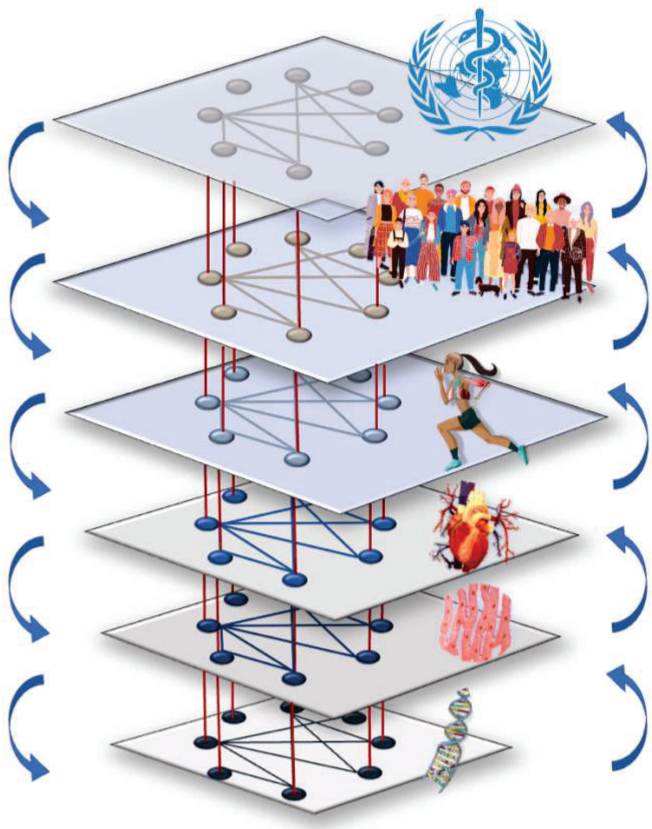
6.1.1. D'una perspectiva unidimensional a una pluridimensional de la salut i l'estat de forma (fitness)

La definició de salut de l'OMS (6), com "un estat complet de benestar físic, mental i social, i no únicament l'absència de malaltia", contrasta amb la definició de Sturmberg (54), que la conceptualitza com "un estat dinàmic, subjectiu i adaptatiu que emergeix de les interaccions en xarxa entre les dimensions biològiques, emocionals, socials i sensorials influenciades per l'entorn".

La figura II mostra la interacció en xarxa dels components i processos fisiològics durant l'exercici. La xarxa fisiològica, niada dins de la xarxa social (comunitària, política, ecològica), interactua tant horitzontal com verticalment mitjançant causalitat circular, és a dir, de baix a dalt i viceversa (55,56). Els nivells socials, més estables que els personals (56), tenen un impacte molt significatiu sobre la xarxa fisiològica, de manera que les polítiques de salut adoptades per organitzacions com l'OMS repercuteixen de forma decisiva en la salut de les persones.

Des d'aquesta perspectiva multinivell, la salut és el resultat de les interdependències dinàmiques entre el medi extern i la xarxa fisiològica que s'adapta de forma continua als reptes socio-psicobiològics. A causa de la seva naturalesa dinàmica i depenent del context, l'estat de la xarxa pot canviar en resposta a condicions somàtiques, connexió social, estats emocionals i semiòtica (54). Per tant, les recomanacions d'exercici cal que s'adaptin als contextos personals canviants, és a dir, siguin realment personalitzades.

Figura II. Representació esquemàtica de la perspectiva de la Fisiologia de Xarxes de l'Exercici.



Font: Adaptada de Balagué i col, (55).

El fitness, per la seva banda, ha estat reduït a dues dimensions condicionals: la força muscular i la resistència; i s'ha quantificat objectivament a través de la despesa energètica (7). Tanmateix, la concepció de fitness no s'ajusta a la seva definició biològica, on el més apte no és el més fort i resistent sinó el més divers, el que té major **potencial de diversitat funcional** (57,58) i conseqüentment, majors possibilitats d'adaptabilitat als reptes de l'entorn.

6.1.2. De desenvolupar atributs condicionals a desenvolupar el potencial de diversitat funcional

En el context dels SCA, el potencial de diversitat funcional és la capacitat dels organismes per evitar o superar estats de funcionalitat reduïda causats per l'envelliment, la fatiga, les lesions, la malaltia o altres pertorbacions inesperades i que permet augmentar les possibilitats de supervivència (57,59). Encara que el desenvolupament dels nivells de força o resistència impliquen major diversitat funcional, aquesta propietat no es pot reduir només a aquests atributs. El fitness inclou múltiples dimensions de l'organisme i, en conseqüència, no es pot desenvolupar únicament en contextos específics com centres de fitness o gimnasos. Una rutina d'exercicis, tal com proposa l'OMS, és només una opció més que pot ser adequada per a les persones que busquen fer sempre el mateix.

El potencial de diversitat funcional es desenvolupa creant sinergies funcionals entre components i processos fisiològics de qualsevol nivell (molecular, cel·lular, tissular, sistèmiques, etc.) que permeten una recuperació eficaç i ràpida de les pertorbacions internes i externes de l'organisme (60–64). Per exemple, les sessions d'exercici intens poden causar fatiga aguda i reducció del potencial de diversitat funcional a curt termini, però també l'augmenten a mig i llarg termini anticipant posteriors pertorbacions (57). A través d'estímuls d'entrenament variats i no repetitius, es promou la diversitat funcional (58). Per exemple, aixecar-se més d'hora per anar en bicicleta a la feina, escalar un cim de muntanya el cap de setmana o patinar a les tardes amb els amics afavoreix aquesta diversitat.

6.1.3. De les receptes universals als criteris d'intervenció/entrenament sensibles al context

El fitness i la salut es poden promoure mitjançant una amplia gamma d'activitats físiques i dosis d'exercici. En aquest sentit, el moviment, com activitat humana fonamental i natural, es promou de forma més efectiva a través d'activitats significatives i adaptades als diferents contextos individuals. Donat que les limitacions personals i ambientals poden canviar de manera inesperada, sembla més adequat ajustar el programa d'exercici a les circumstàncies i no al revés (65).

Tal i com mostren els resultats de l'estudi de la tesi, la possibilitat de que els participants triessin els entorns físics i socials per a la pràctica d'exercici (en un parc, a la muntanya, amb la família o amb els amics), així com la diversificació de les modalitats d'activitat física, va permetre l'adquisició d'una major consciència del benestar en relació a l'exercici. Altres estudis mostren que les respostes afectives més positives es produeixen quan les persones trien activitats que perceben com significatives, en contrast amb les prescripcions d'exercici tancades (66). Tot i que en algunes situacions específiques les receptes d'exercici i les instruccions professionals poden ser necessàries (pacients amb malalties cròniques, individus amb hàbits sedentaris o persones fatigades); uns criteris d'entrenament sensibles al context faciliten una millor adaptació a les necessitats individuals, aconseguint una personalització real.

6.1.4. Del centre de fitness al contacte amb la natura

Les activitats promocionades en les recomanacions d'exercici solen ser les realitzades en entorns tancats com gimnasos. Sorprenentment, l'ús d'entorns naturals per la realització d'exercici físic, com parcs, boscos, muntanyes, platges, etc., no estan prou contemplat. Tanmateix, alguns estudis mostren que persones amb accés a espais verds (67) i costers (68) no només tendeixen a mantenir nivells més alts d'activitat física, sinó que també redueixen l'estrès i milloren el benestar personal (69). Caminar pel parc, per exemple, indueix respostes afectives més positives que fer-ho en entorns urbans (70). A més, a nivell fisiològic, s'ha observat que la freqüència cardíaca, la conductància de la pell, la tensió muscular i el temps de recuperació del pols es restableixen més ràpidament quan les persones es troben en entorns naturals en comparació amb els entorns urbans (71).

Els principals determinants de la salut sovint estan més vinculats amb l'entorn en què vivim i les relacions socials que mantenim (72). Entendre i abordar aquests determinants socials i ambientals és fonamental per millorar la salut de la població. En aquest sentit, tant els espais naturals com la interacció social comunitària juguen un paper clau en la promoció de la salut i el benestar (73), especialment per aquells que teletreballen a casa o en entorns sense finestres. Així doncs, prioritzar l'activitat física en espais naturals o a l'aire lliure és considerat més efectiu per promoure un estil de vida actiu i saludable.

6.1.5. De la dependència a l'autoeficàcia en les recomanacions d'exercici per a la salut

La prescripció d'exercici per a la salut té un enfocament dominantment unidireccional, del professional cap a l'usuari/a, qui es troba en una posició de dependència constant de les directrius i instruccions del professional. El/la professional que aplica estrictament les directrius de l'OMS, no té en compte els valors, objectius i desitjos personals dels usuaris/àries, ignora les seves motivacions i el seu context, com l'accés a les instal·lacions esportives, el suport social o les activitats físiques preferides.

La creació de programes d'exercici personalitzats requereix d'una cooperació mútua entre professional i usuari/a. És essencial cuidar la interacció entre ambdues parts per passar d'una relació de dependència a una de major autonomia en la gestió de la salut i el fitness. Això implica una revisió dels rols que promogui una participació activa de l'usuari/a i una presa de decisions conjunta. Quan els participants acorden amb el/la professional els objectius i el programa a seguir i aquest s'adapta a les seves necessitats, motivacions i capacitats immediates, s'observen millores significatives en les respostes afectives i en la condició física (66,74). Les directrius haurien de promoure aquest canvi de rols i una relació més col·laborativa i inclusiva entre professionals i usuaris/àries.

6.1.6. De la prescripció al co-disseny de programes d'exercici

Sota la perspectiva de la NPE, els professionals i les usuàries/pacients/esportistes haurien de formar un sistema de co-aprenentatge. D'aquesta manera els/les professionals passen de ser simples prescriptores a co-dissenyadores i co-aprenents, i els/les usuaris/àries passen de ser executores passives a participants actius (65).

El/la professional guia i proposa noves activitats per ajudar a l'usuari/ària a explorar diferents possibilitats i promoure el desenvolupament del seu potencial de diversitat funcional. Les pràctiques motivants i reptes significatius poden produir més beneficis psicològics que les recomanacions universals d'exercici, conduint a una major adherència (75–78). A més, les activitats prou desafiants semblen satisfer les necessitats psicològiques bàsiques (79). A través de l'exposició a diferents pràctiques i de preguntes que inviten a la reflexió, el/la professional ajuda a l'usuari/ària a expandir la seva consciència interoceptiva.

Aquesta consciència, sovint ignorada en el context de la prescripció d'exercici, ajuda a l'usuari/ària a integrar dimensions fisiològiques, psicològiques, socials, etc., que afecten al seu estat en relació amb l'entorn, i a prendre decisions adequades. L'estat fisiològic pot canviar a un ritme relativament ràpid en funció de la qualitat del són, l'estat de fatiga, l'estat psicoemocional o el clima, entre altres (56,58,60). Per això, els ajustos continus de les activitats i càrregues d'entrenament són molt necessaris. La consciència interoceptiva possibilita també la detecció de potencials efectes adversos de l'entrenament com són el sobre-entrenament o les lesions, i potencia una adaptació saludable i l'adquisició d'un estat de fitness multidimensional (80). La implementació d'eines d'avaluació subjectiva amb finalitats pedagògiques i exploratòries també poden contribuir substancialment a reconèixer i adquirir un estat saludable (54,58).

La implicació de la usuària/pacient/esportista com a co-dissenyador/a de la intervenció no només és crucial per augmentar l'adhesió a l'exercici, sinó que té efectes positius sobre la salut mental i l'autonomia en adults sans (81–83). A més, l'usuari/a co-aprèn amb l'ajuda del/de la professional i es fa menys dependent de receptes. L'objectiu final és ajudar a l'usuari/ària a passar de la dependència a l'autoeficàcia, desenvolupant més adherència cap a l'activitat física.

Les experiències de co-disseny mostren que pacients i professionals poden treballar junts d'una manera significativa i sostenible (84–87). No obstant, les oportunitats de co-disseny solen estar restringides a usuaris/àries amb una situació socioeconòmica i una educació superiors. Per això, les directrius d'exercici per a la salut han de proporcionar criteris generals que fomentin comportaments individuals proactius, exploratoris i creatius. En l'estudi experimental de la tesi, únicament el grup del co-disseny va experimentar millores en la salut mental, mentre que el grup que seguia la prescripció va manifestar un augment en els nivells d'ansietat, depressió i estrès, mesurats a través del qüestionari *Depression Anxiety Stress Scale 21* (DASS-21) i verbalitzats a les entrevistes personals que es van fer durant i després del programa. Aquesta diferència pot ser atribuïda a la pressió que implica seguir un programa d'exercici prefixat, independentment de les limitacions i condicionants diaris, com els períodes de vacances, les visites familiars o la càrrega de treball (88).

Només el grup que va participar en una intervenció co-dissenyada va expressar el desig de continuar amb el programa en el futur, la qual cosa pot explicar-se per la valència afectiva positiva experimentada durant i després de l'exercici (89). En contraposició, el grup que va seguir la prescripció va reportar monotonia i manca de motivació per la falta de canvis en la rutina diària.

La monotonia de les recomanacions d'exercici és un factor clau que pot afectar l'adherència a l'exercici (24,90). Inclús els esportistes que entrenen diàriament en la mateixa disciplina poden veure reduïda la seva motivació a causa de l'avorriment (91). En canvi, no s'han observat aquests efectes negatius en els participants que s'han involucrat en activitats noves i desafiants (92). La diversitat d'activitats i la seva capacitat per proporcionar diversió són elements crítics per a un compromís a llarg termini i una millor adherència a l'exercici físic per la salut (91,93,94). Per exemple, la participació en activitats grupals, amb la família o amb amics s'ha demostrat que fomenten la continuïtat en la pràctica de l'exercici físic (95).

Com a resum, el/la professional i l'usuari/a haurien de centrar-se en seleccionar propostes significatives, adaptades, variades i prou desafiants per desenvolupar el potencial de diversitat funcional. La taula III resumeix i contrasta algunes de les característiques de prescriure i co-dissenyar, respectivament.

Taula VII. Contrast de metodologies d'exercici físic per la salut basades en la prescripció i el co-disseny.

Metodologia	Prescripció	Co-disseny
Rol dels professionals	Prescriptors/es	Educador/a i co-aprenent
Rol dels pacients	Executors/es	Co-dissenyadors/es

Relació professional-pacient	Dependència	Autonomia
Contingut	Recomanacions universals (píndoles d'exercici)	Criteris personalitzats
Objectiu	Despesa calòrica, desenvolupament de la capacitat aeròbica i la força	Desenvolupament del potencial de diversitat funcional i la consciencia interoceptiva
Tasques	Exercicis aeròbics i de força imposats	Exercicis contextualment significatius, motivant i co-dissenyats
Activitat	Repetitiva i monòtona	Significativa, estimulant i motivant
Metodologia	Pre- planificada basada en la prescripció	Personalitzada i contextualitzada, orientada a l'autoregulació
Dosificació	Progressiva (volum i intensitat)	Balanç entre requisits i capacitats immediates
Monitorització	Objectiva amb l'ús de dispositius externs	Subjectiva, guiada per la consciència interoceptiva i somàtica
Lloc	Centre de fitness	Segons preferències individuals, millor a l'aire lliure

Font: Elaboració pròpia

6.2. Limitacions i perspectives de futur

És important esmentar algunes limitacions d'aquesta tesi. En primer lloc, portar a terme intervencions tenint en compte les propietats dels SCA en entorns d'exercici físic per la salut és un repte per als professionals i els/les usuaris, donat el limitat coneixement d'aquestes propietats. Els professionals sovint no estan familiaritzats amb els supòsits teòrics, metodològics i pràctics de les guies de prescripció d'exercici físic. A més, els/les usuaris tendeixen a percebre l'exercici com una obligació en lloc de comprendre'l com un potenciador de la salut en múltiples dimensions, que van més enllà dels aspectes purament fisiològics. La novetat de la perspectiva que s'exposa a aquesta tesi (NPE), la seva aplicació en l'àmbit de l'exercici físic, i la necessitat de formació dels professionals en la perspectiva, fa que sigui necessari un esforç addicional per difondre'n el coneixement i promoure la seva implementació efectiva.

Per a futurs estudis, es recomana investigar els efectes del co-disseny en altres poblacions, com pacients crònics i diferents grups d'edat. També és important explorar les diferències sexuals, ja que en l'estudi experimental no es van poder dur a terme a causa del reduït nombre de participants.

7. Conclusions

1. Les recomanacions d'exercici per a la salut de l'OMS, basades en supòsits teòrics i metodològics sobresimplificats, mostren limitacions en les possibilitats de personalització i adherència de la població a l'exercici.

2. Els supòsits teòrics identificats son la reducció del fitness als atribut físics de resistència aeròbica i força, la universalitat de les recomanacions i la manca de consideració dels canvis de la persona amb el temps i el context.

3. Entre els supòsits metodològics estan les relacions lineals entre càrrega i rendiment, els dissenys experimentals basats en la comparació de mitjanes grupals de variables aïllades, la sensibilitat de les esmentades variables als canvis de condició física, la generalització de resultats a la població a partir de l'estadística inferencial, y la inferència de resultats de variabilitat intraindividual a la interindividual.

4. La tesi proposa una actualització d'aquestes recomanacions basada en les propietats dels SCA i la perspectiva de la NPE.

5. A través de l'aplicació dels principis de la NPE s'han elaborat uns criteris d'intervenció personalitzats, específicament adaptats al context del teletreball, com són: la participació activa de l'usuari/a en el seu propi procés, la selecció d'activitats basades en les motivacions personals, la possibilitat d'exploració de noves formes de moviment i activitat, la manipulació del context físic per reduir el temps d'immobilitat i el desenvolupament de la consciència interoceptiva, clau per aconseguir una auto-monitorització i autoregulació saludable de l'exercici.

6. Una intervenció personalitzada, basada en els principis de la NPE, ha demostrat un major impacte en la salut mental, la consciència interoceptiva, l'autonomia i l'auto-regulació de l'exercici en comparació amb una intervenció basada en les recomanacions de l'OMS. És important que els professionals i les organitzacions sanitàries tinguin present que la personalització de les recomanacions d'exercici reclama el desenvolupament de l'auto responsabilitat de l'usuari/a envers la seva salut, i això suposa la implementació d'una acció pedagògica per part del professional.

7. Les futures recomanacions d'exercici haurien d'orientar-se especialment a (a) actualitzar els conceptes de salut i fitness de professionals i usuaris/àries, re-dirigint els objectius de les intervencions, (b) dissenyar pràctiques adreçades a desenvolupar el potencial de diversitat funcional i la consciència interoceptiva, (c) fomentar processos de co-adaptació i co-aprenentatge entre professionals i usuaris/àries, (d) crear contextos que ofereixin possibilitats de moviment funcionals i significatius.

8. La perspectiva teòrica i metodològica de la NPE introduïda en aquesta tesi, ofereix la possibilitats d'actualitzar i personalitzar realment les recomanacions actuals d'exercici per la salut, incorporant elements clau com la participació activa de l'usuari/a i la consciència del seu propi procés de salut.

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Annexos

Prescribing or co-designing exercise in healthy adults? Effects on mental health and interoceptive awareness

- Resum:

Introducció: Les recomanacions universals d'exercici de l'OMS, ignorant les preferències individuals i els contextos canviants, no personalitzen de forma real. En base a una re-definició del fitness i a una concepció persona-entorn derivada de l'aplicació de principis de la NPE, es proposa en el teletreball una participació activa dels usuaris/àries en les intervencions d'exercici capaç de desenvolupar la seva consciència interoceptiva.

Objectiu: contrastar els efectes sobre la condició física, la salut mental i la consciència interoceptiva d'una intervenció d'exercici co-dissenyada, basada en els principis de la NPE, amb un programa d'exercici basat en les recomanacions de l'OMS per a adults sans.

Mètode: Vint adults sans (10 homes i 10 dones, de 40 a 55 anys) van participar voluntàriament en la recerca. Es van assignar aleatòriament a una intervenció d'exercici co-dissenyada (grup CoD) i a un programa d'exercici basat en les recomanacions de l'OMS (grup OMS). Supervisats en línia per entrenadors personals especialitzats, els dos programes, equivalents en volum i intensitat, es van aplicar durant 9 setmanes. Els efectes de la intervenció d'exercici es van mesurar a través d'entrevistes personals, que van valorar l'autonomia i auto-regulació de l'exercici, qüestionaris de salut mental (DASS-21) i consciència interoceptiva (MAIA) i una prova d'esforç cardiorespiratòria. Les diferències intra-grup (pre-post) es van avaluar utilitzant la prova de Mann-Whitney Wilcoxon i les diferències inter-grup mitjançant proves t de Student. Les mides de l'efecte es van calcular mitjançant la d de Cohen. Les entrevistes es van valorar mitjançant anàlisi de contingut temàtica.

Resultats: Onze participants van completar la intervenció (CoD = 8, OMS = 5). Ambdós grups van millorar, no significativament, els resultats de les proves cardiorespiratòries, i no es van trobar diferències intergrupals post-intervenció. El grup CoD va millorar la salut mental ($p < 0{,}001$), i la consciència interoceptiva en set de les vuit escales del qüestionari MAIA ($p < 0{,}001$). El grup OMS només va millorar en tres escales del qüestionari MAIA ($p < 0{,}01$). L'anàlisi de contingut de les entrevistes va revelar cinc temes basats en les preguntes formulades: l'adhesió i motivació durant el programa, els inconvenients del programa, l'autoregulació i l'autonomia, l'impacte en l'estil de vida i la consciència interoceptiva. Tots dos grups van coincidir en què ser supervisats per un entrenador personal i rebre feedback constant va facilitar la seva participació. Destacant la

personalització del grup del co-disseny, alguns van continuar la pràctica després de l'intervenció. Els participants que es van retirar del programa de l'OMS ho van fer a causa de la manca de flexibilitat horària i incompatibilitat del programa amb les seves necessitats i contextos personals.

Conclusió: Una intervenció personalitzada basada en els principis de la NPE va ser més efectiva per al desenvolupament de la salut mental, la consciència interoceptiva, l'autonomia i la autoregulació de l'exercici en comparació amb una intervenció basada en les recomanacions de l'OMS.

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Prescribing or co-designing exercise in healthy adults? Effects on mental health and interoceptive awareness

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Universal exercise recommendations for adults neglect individual preferences, changing constraints, and their potential impact on associated health benefits. A recent proposal suggests replacing the standardized World Health Organisation (WHO) exercise recommendations for healthy adults by co-designed interventions where individuals participate actively in the decisions about the selected physical activities and the effort regulation. This study contrasts the effects on mental health and interoceptive awareness of a co-designed and co-adapted exercise intervention with an exercise program based on the WHO recommendations for healthy adults. Twenty healthy adults (10 men and 10 women, 40–55 y.o.) participated voluntarily in the research. They were randomly assigned to a co-designed exercise intervention (CoD group) and a prescribed exercise program (WHO group). Supervised online by specialized personal trainers, both programs lasted 9 weeks and were equivalent in volume and intensity. The effects of the exercise intervention were tested through personal interviews, questionnaires (DASS-21 and MAIA) and a cardiorespiratory exercise test. Intragroup differences (pre-post) were assessed using the Mann-Whitney Wilcoxon test and intergroup differences through Student's *t*-tests. Effect sizes were calculated through Cohen's d. Interviews were analyzed through thematic analysis. Eleven participants completed the intervention (CoD = 8, WHO = 5). Both groups improved, but non significantly, their cardiorespiratory testing results, and no differences were found between them post-intervention. Mental health was only enhanced in the CoD group ($p < 0.001$), and interoceptive awareness improved in seven of the eight scales in the CoD group ($p < 0.001$) and only in 3 scales in the WHO group ($p < 0.01$). In conclusion, the co-designed intervention was more effective for developing mental health, interoceptive awareness, autonomy, and exercise self-regulation than the WHO-based exercise program.

KEYWORDS

personalized exercise, mental health, affective wellbeing, complex systems approach, network physiology of exercise, WHO recommendations, exercise adherence, self-awareness

Introduction

Prescribing an adequate exercise program to promote health in the adult population has been a central research issue (Pollock et al., 2000). Two main types of programs (aerobic, resistance, and a combination of both) have been investigated due to their different physiological impact and proven benefits (Kenney et al., 2015). Based on the available research, the American College of Sports Medicine (ACSM) and the World Health Organization (WHO) have converged on the type of activity and minimum dose in their guidelines for exercise prescription in health and disease (Riebe et al., 2018) with light adaptations depending on the age and type of disease (Bull et al., 2020; Bushman, 2020). However, some authors have questioned the theoretical and methodological assumptions of this one-size-fits-all approach (Balagué et al., 2020a), and have proposed person-centered guidelines in line with current therapeutic tendencies (Carpinelli, 2009; Greenhalgh et al., 2014; Zimmer et al., 2018; Wackerhage and Schoenfeld, 2021).

The self-determination theory (SDT)-based exercise referral consultation (Jolly et al., 2009; Deci and Ryan, 2013) proposes interviewing participants before the exercise program about their perceptions of autonomy and motivational regulations. The aim is provide choices of activities, support initiations and relevant information for being physically active. Limiting their intervention to the beginning of the program, professionals do not guide adaptations during the program. However, a permanent interaction professionals-practitioners during this period may ensure adequate adjustments of exercise characteristics to keep participant's wellbeing and adherence, and develop their self-knowledge and autonomy.

It is known that meaningful and motivating practices increase exercise adherence and, thus, its health-related effects (Salmon, 2001; Williams, 2008; Carek et al., 2011; Stonerock et al., 2015). Additionally, performing new and challenging activities seem to satisfy basic psychological needs (Fernández-Espínola et al., 2020).

The effects of regular exercise on depression and anxiety, the two most disabling mental disorders in both sexes, and among the top 25 leading causes of the global health-related burden (GBD 2019 Diseases and Injuries Collaborators, 2020) are well known. Mental health and emotional wellbeing improve through regular exercise (Paluska and Schwenk, 2000; Ströhle, 2009; Stanton and Reaburn, 2014; Schuch et al., 2016), and is also associated with a reduced risk of suffering from emotional disorders (Bernstein and McNally, 2018).

From a complex systems perspective, health has been defined as a dynamic product of the interplay between the external environment and internal physiology (Sturmberg et al., 2019). The health state can change in response to somatic conditions, social connectedness, emotional feelings, and subjective perceptions (Sturmberg, 2019). Within this paradigm, the stability of a healthy state can be achieved in multiple ways, and nonlinear, i.e., non-proportional, individual training effects may occur after exposure to exercise and training loads (Hristovski and Balagué, 2010). Even the same exercise intensity, which may promote positive adaptations in a specific person or context, may produce overtraining or no effects in another person or particular context (Hristovski et al., 2010).

The ACSM and the WHO recommend performing a minimum of 150 min of aerobic exercise at a moderate intensity or 75 min of vigorous-intensity exercise in combination with resistance training at least two times per week, using two sets of 8–15 repetitions with 60% of one-repetition maximum (American College of Sports Medicine, 2017; World Health Organization [WHO], 2020). These universal recommendations assume the existence of decontextualized realities (Jones et al., 2017) and ideal or prototypic fitness and health states. Although fitness is often associated with strength and conditioning, the fittest is not the strongest or endured in biological evolution but the most diverse (Pol et al., 2020). Accordingly, fitness has been redefined as the ability to survive in a broad range of contexts to adapt to socio-psycho-biological challenges (Balagué et al., 2020b; Hristovski and Balagué, 2020).

Even though most studies present favorable results applying the recommended types of exercise, systematic reviews and meta-analyses on exercise prescription indicate the lack of high-quality studies showing the sustainability of standardized programs (Sørensen et al., 2006) and the need for personalizing the recommendations (Zimmer et al., 2018). In line with personalized exercise medicine, it has been advised to reorient the main aims of exercise prescription and redefine the roles of health care exercise professionals interacting with users/patients (Balagué et al., 2020b). Notably, it has been suggested to develop the autonomy and self-regulation of users/patients through their active involvement in the co-design of exercise proposals and workload adjustments (Almarcha et al., 2021).

Due to substantial inter-individual differences and personal contexts, the development of interoceptive awareness of users/patients seems crucial for achieving self-knowledge and self-responsibility to select and regulate exercise workloads adequately (Pol et al., 2020; Montull et al., 2022). Interoceptive awareness is the ability to identify, access, understand, and respond appropriately to the patterns of internal signals that allow to engage in life challenges and ongoing adjustments (Craig, 2015). Regulating daily active and resting periods, frequency, intensity, and duration of exercise promotes healthy mind-body states. Almarcha et al. (2021) sustain that education on self-regulation of psycho-emotional and physical states is essential to promote health and affective wellbeing during home-based teleworking. The authors propose to healthcare professionals: (a) redefine fitness states, (b) refocus the aims of home-based exercise, (c) guide users from dependency to autonomy, (d) promote co-adaptive and co-learning processes, and (e) develop interoceptive awareness. As far as we know, no studies have evaluated the interoceptive awareness effects of a co-designed exercise program in healthy adults.

The present study aimed to contrast the effects of a co-designed exercise intervention with a WHO-based program on mental health and interoceptive awareness in healthy adults. Specifically, it was hypothesized that a co-designed intervention reduced further depression, anxiety, and stress levels and increased further interoceptive awareness and self-regulation.

Materials and methods

Participants

Twenty healthy adults (10 men and 10 women) aged between 40 and 50 y.o., with a medium socioeconomic status, higher education level and non-involved in regular physical activity, volunteered to participate in this study. Considering a target power of 0.8, a significance level of $p < 0.05$, and a medium effect size (0.5), the total sample size calculated using the software G * Power v3.1.9.7 was 12 participants. To compensate for the possible loss of follow-up, the proposed sample was 20 participants.

The exclusion criteria were the following: (a) report any contraindications and injury that prevented from physical exercise; (b) prohibitions of physical testing interventions; and (c) pacemaker dependent, not in sinus rhythm, pregnant, had a BMI greater than 30 kg/m^2 or had known carotid or femoral artery stenosis.

After being informed about the study procedure and sign an informed consent, participants performed a cardiorespiratory exercise test and responded to two questionnaires (see below) through Google forms. All responses were coded to ensure data privacy and anonymity. After it, they were randomly divided into two groups of 10 members each that followed two different exercise programs during 9 weeks: (a) a co-designed exercise intervention (CoD group), and (b) a standardized exercise program based on WHO recommendations (WHO group). Both groups had similar fitness status and questionnaire scores. Participants were randomly assigned to 7 personal trainers (Sport Science graduates) with a minimum of 3 years of professional experience and specifically trained for 2 weeks to develop both intervention programs. Each coach trained virtually 2–3 participants. They supervised participants' online training and interacted with them twice a week. They also had meetings with the research coordinator to follow up on the intervention weekly. The research project was approved by the Comité d'Ètica d'Investigacions Clíniques de l'Administració Esportiva de Catalunya (ref. 07/2015/CEICEGC). A total of 7 participants (CoD = 2, WHO = 5) did not complete the intervention program.

Procedure

Co-designed exercise intervention

It had two main objectives: (a) promote health through co-designing meaningful and personally motivating activities, and (b) develop the participant's autonomy, self-responsibility and interoceptive awareness. Participants proposed activities they liked to do or would like to try. Personal trainers also suggested activities that could be meaningful and motivating for the participant, not only those based on cyclic or repetitive movements (Almarcha et al., 2021). For example: playing with their kids, doing outdoor activities, playing exergames, stretching at the office, and using the bicycle for displacement, among others.

Standardized exercise program based on World Health Organization recommendations

It consisted of cycling or running exercises, performed 5 days per week at low intensity or 3 days per week at vigorous-intensity with a minimum duration of 25–30 min per session, according to the WHO guidelines (World Health Organization [WHO], 2019). The strength training consisted of a 12-station High-intensity circuit (Klika and Jordan, 2013) performed twice a week according to the American College of Sports Medicine Guidelines (ACSM) (Bushman, 2020). All exercises could be done with bodyweight in almost any setting (e.g., home, office, hotel room, etc.). Exercises were performed for 30 s, with 10 s of transition time between bouts. The total time for the entire circuit workout was approximately 7 min. The circuit could be repeated 2–3 times. Load intensity and volume were adjusted weekly to keep a rate of perceived exertion (Borg CR 10 Scale) of 3–5 in all sessions (see **Table 1**).

TABLE 1 Comparison of the characteristics of the exercise program based on WHO recommendations and the co-designed intervention.

Type of program	WHO exercise program (WHO)	Co-designed intervention (CoD)
Foundation	WHO and ACSM guidelines	Co-designed
Exercise	Repetitive	Varied
Frequency	Aerobic: 5 d/w Strength: 2 d/w	5 d/w
Intensity	Aerobic: RPE (CR 10): 3–5 Strength: RPE (CR 10): 8	RPE (CR 10): 3–5
Duration	300 min/week	300 min/week
Type of activity	Aerobic (running, cycling), strength	Based on individual preferences

Testing

A cardiorespiratory exercise test and two questionnaires (see below) were administered pre-and post-intervention, and a personal interview was performed at the end of the intervention. The cardiorespiratory exercise test was supervised by medical staff that confirmed the health status of the participants. The questionnaires were responded online using Google Forms, and an external researcher performed the personal video conference interviews.

Cardiorespiratory exercise test

An incremental cycling test (Excalibur, Lode, Groningen, Netherlands) starting at 50 W and increasing the workload by 30 W/min until reaching a subjective rate of perceived exertion (CR-10 scale) of "very hard" (RPE $\geq$ 8) was performed. Participants breathed through a valve (Hans Rudolph, 2700, Kansas City, MO, United States), and the respiratory gas exchange was determined using an automated open-circuit system (Metasys, Brainware, La Valette, France). Oxygen and CO2 content and airflow rate were recorded breath by breath. An electrocardiogram (ECG) was continuously monitored (DMS Systems, DMS-BTT wireless Bluetooth ECG transmitter and receiver, software DMS Version 4.0, Beijing, China). The test was performed in a well-ventilated lab; the room temperature was 23°C and the relative humidity 48%, with variations of no more than 1°C in temperature and 10% in relative humidity. The tests were carried out at least 3 h after a light meal, and participants were instructed not to perform vigorous physical activity for 72 h before testing.

Questionnaires

Depression, Anxiety and Stress scales (DASS-21)

The Spanish version of the DASS-21 questionnaire (Bados et al., 2005) assessed the self-reported negative emotional states during the last week. This questionnaire contains 21 statements rated on a four-categories of Likert scale (from 0 = "does not apply to me at all" up to 3 = "it applies a lot to me most of the time"), distributed along with three subscales (with seven items each): Depression, Anxiety and Stress (Lovibond and Lovibond, 1995). The depression scale assesses dysphoria, hopelessness, devaluation of life, lack of interest/involvement and inertia (e.g., I was unable to become enthusiastic about anything). The anxiety scale assesses autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect (e.g., I was aware of the action of my heart in the absence of physical exertion). The stress scale is sensitive to levels of chronic non-specific arousal. It assesses difficulty relaxing, nervous arousal, and being easily upset/agitated, irritable/over-reactive and impatient (e.g., I was intolerant of anything that kept me from getting on with what I was doing).

Scores for depression, anxiety and stress are calculated by summing the scores for the relevant items. The values of Cronbach's alpha and test-retest reliability indicate good internal consistency of the Spanish version of DASS-21 (Bados et al., 2005).

Multidimensional Assessment of Interoceptive Awareness

The Spanish version of the multidimensional assessment of interoceptive awareness (MAIA) questionnaire (Valenzuela-Moguillansky and Reyes-Reyes, 2015) was administered. It is a self-report instrument developed by Mehling et al. (2012) to measure eight dimensions of interoceptive body awareness. The noticing scale assesses the awareness of uncomfortable, comfortable or neural body sensations (e.g., when I am tense, I notice where the tension is located in my body). The not distracting scale assesses the tendency not to use distraction to cope with discomfort (e.g., when I feel pain or discomfort, I try to power through it). The not worrying scale assesses the tendency to not experience emotional distress with physical discomfort (e.g., I can notice an unpleasant body sensation without worrying about it).

The attention regulation scale assesses the ability to sustain and control attention to body sensations, (e.g., I can maintain awareness of my inner bodily sensations even when a lot is going around me). The emotional awareness scale assesses the ability to attribute specific physical feelings to physiological manifestations of emotions (e.g., When something is wrong in my life, I can feel it in my body). The self-regulation scale assesses the ability to regulate distress by attention to body sensations (e.g., I can use my breath to reduce tension). The body listening scale assesses the tendency to actively listen to the body for insight (e.g., I listen to my body to inform me about what to do). The trusting scale assesses the experience of one's body as safe and trustworthy (e.g., I feel my body is a safe place). It has 32 items tested on a Likert scale, with six levels of ordinal response coded from 0 (never) to 5 (always), generating a total direct score on a scale that ranges from 0 to 160 points. The Spanish version showed appropriate construct validity and reliability indicators, with a Cronbach's α of 0.90 for the total scale and values between 0.40 and 0.86 for the different subscales (Valenzuela-Moguillansky and Reyes-Reyes, 2015).

Interviews

Participants were invited to a 30-min semi-structured video conference interview by a researcher external to the intervention to avoid bias. The semi-structured interview guides the intervention's critical points while allowing new themes/issues to emerge. The reliability of the interviews was guaranteed by the same interviewer, the same design scheme of the questions, the same length of interrogation and the same period for all interviews. The interviews were video recorded and transcribed verbatim. Two experienced qualitative researchers and five Sport Science professionals validated the interview guide before the study. It consisted of questions concerning: previous experiences, reasons for involvement in the exercise program, perceived benefits or challenges to participating, and the role of the personal trainer (e.g., Do you think the figure of the personal trainer is essential to continue with the level of physical activity achieved?) reasons to drop out/adherence, what they have learned (e.g., Have you gained resources to adapt the exercise to any personal and environmental situation?) and readiness to implement changes in their lifestyle behavior beyond the program (e.g., Have you discovered any physical activities to incorporate into your habits?).

Data analysis

Physiological testing

The ratio between the workload corresponding to the RPE $\geq$ 8 and the oxygen uptake relative to body weight (VO_2) at this workload (W/VO_2) and the ratio between the workload corresponding to the RPE $\geq$ 8 and the heart rate (HR) at this workload (W/HR) were compared pre-and post-intervention using Wilcoxon matched-pairs test and independent samples *t*-test.

Questionnaires

Means with 95% confidence intervals, medians, standard deviations, and interquartile ranges were calculated to assess the location and dispersion of scores obtained in DASS-21 and MAIA. Skewness and kurtosis were used to determine the shape and normality of the distribution of scores. Intragroup pre-post differences were evaluated using paired *t*-tests and intergroup differences through independent samples *t*-tests. Effect sizes were calculated through Cohen's d. All quantitative statistical analyses were conducted using SPSS (version 25, IBM Corp).

Interviews

All interview transcripts were cross-checked with video recordings to ensure accuracy. Identification codes were assigned [WHO, CoD or NC -non-completer-, with consecutive numbers (e.g., CoD4)]. Thematic analysis was employed to identify emergent themes until saturation was reached (Braun and Clarke, 2006). Two researchers independently reviewed one transcript to identify codes using NVIVO software (version 2, QRS International Pty Ltd). Then, they discussed the findings and presented the proposed principles derived from the data to the research team until consensus was reached on the final regulations.

Results

Physiological testing

No differences in W/VO_2 and W/HR were found pre-post intervention in both groups (WHO and CoD) nor between groups.

Questionnaires

All participants responded to DASS-21 and MAIA questionnaires, but only 13 of them completed the intervention (CoD = 8, WHO = 5).

Depression, anxiety and stress levels

DASS questionnaire descriptives are presented in **Table 2**. After the intervention, the CoD group improved their scores in the three dimensions of the DASS-21 questionnaire: depression [$t(7) = 7.907$, $p = 0.0001$], anxiety ($t = 27.032$, $p = 0.0001$) and stress ($t = 8.973$, $p = 0.0001$). However, no differences were detected in the WHO group. Intergroup differences showed higher anxiety (W = 36.000, Z = –3.038, $p = 0.002$, d = 0.84) and stress (W = 39.500, Z = –2.449, $p = 0.011$, d = 0.68) in the WHO group compared to the CoD group.

Interoceptive awareness

MAIA questionnaire descriptives are presented in **Table 3**. After the intervention, the CoD group improved in 7 of the 8 scales of the MAIA questionnaire: noticing [$t(7) = -1.276$, $p = 0.0001$], not-distracting [$t(7) = -4.492$, $p = 0.003$], attention regulation [$t(7) = -26.839$, $p = 0.0001$], emotional awareness [$t(7) = -13.642$, $p = 0.0001$], self-regulation [$t(7) = -13.316$, $p = 0.0001$], body listening [$t(7) = -7.848$, $p = 0.0001$], trusting [$t(7) = -10.991$, $p = 0.0001$] except for not-worrying [$t(7) = -1.276$, $p = 0.243$]. In the WHO group, differences were detected only in 3 scales, self-regulation [$t(4) = 4.376$, $p = 0.012$], body listening [$t(4) = -6{,}144$, $p = 0.004$], and trusting [$t(4) = -6{,}364$, $p = 0.003$].

Post intervention inter-groups differences were observed in noticing (W = 20.500, Z = –2.140, $p = 0.030$, d = 0.59), non-distracting (W = 18.500, Z = –2.442, $p = 0.011$, d = 0.68), attention regulation (W = 16.000, Z = –2.789, $p = 0.003$, d = 0.77), self-regulation (W = 15.000, Z = –2.956, $p = 0.002$, d = 0.81), listen to body signals (W = 15.000, Z = –2.952, $p = 0.002$, d = 0.82) and trust (W = 15.000, Z = –3.029, $p = 0.002$, d = 0.84) in favor of the CoD group.

Interviews

All participants were interviewed, including those who did not complete the entire intervention. The thematic analysis

TABLE 2 DASS questionnaire items descriptives.

	Group	*N*	Mean	*SD*	Variance	Skewness	SE	Kurtosis	SE
PRE_Depression	CoD	8	12.250	4.46	19.93	1.0261	0.752	−0.234	1.48
	WHO	5	8.400	7.80	60.80	1.9861	0.913	3.948	2.00
POST_Depression	CoD	8	1.500	1.41	2.00	0.4041	0.752	−0.229	1.48
	WHO	5	6.000	4.24	18.00	−0.5238	0.913	−0.963	2.00
PRE_Anxiety	CoD	8	13.000	1.51	2.29	−1.3229	0.752	0.875	1.48
	WHO	5	9.200	5.93	35.20	−0.8849	0.913	1.449	2.00
POST_Anxiety	CoD	8	0.750	1.04	1.07	0.6441	0.752	−2.240	1.48
	WHO	5	10.000	2.45	6.00	1.3608	0.913	2.000	2.00
PRE_Stress	CoD	8	17.750	4.83	23.36	−0.5353	0.752	−0.744	1.48
	WHO	5	8.800	5.76	33.20	−0.0376	0.913	−1.804	2.00
POST_Stress	CoD	8	4.000	3.02	9.14	0.3307	0.752	−1.488	1.48
	WHO	5	14.400	9.42	88.80	1.4646	0.913	2.443	2.00

TABLE 3 MAIA questionnaire items descriptives.

	Group	*N*	Mean	*SD*	Variance	Skewness	SE	Kurtosis	SE
PRE_Noticing	CoD	8	1.91	0.7063	0.4989	−0.7578	0.752	2.4997	1.48
	WHO	5	2.10	0.5477	0.3000	1.5310	0.913	1.7448	2.00
POST_Noticing	CoD	8	4.25	0.7440	0.5536	−1.2140	0.752	1.5595	1.48
	WHO	5	4.55	0.4472	0.2000	−0.0524	0.913	−2.3242	2.00
PRE_Not- distracting	CoD	8	2.92	0.3897	0.1518	1.3533	0.752	0.6000	1.48
	WHO	5	2.80	0.1807	0.0327	0.6086	0.913	−3.3333	2.00
POST_Not-distracting	CoD	8	4.08	0.6357	0.4041	−1.7759	0.752	4.0011	1.48
	WHO	5	4.27	0.4349	0.1891	−0.5215	0.913	−1.5244	2.00
PRE_ Not-worrying	CoD	8	2.08	1.3060	1.7056	0.3178	0.752	−0.1760	1.48
	WHO	5	2.20	1.3431	1.8039	1.0194	0.913	2.0429	2.00
POST_Not-worrying	CoD	8	2.59	0.3908	0.1527	−0.8853	0.752	−0.4606	1.48
	WHO	5	2.73	0.0158	2.50e-4	1.40e-14	0.913	−1.2000	2.00
PRE_ Attention regulation	CoD	8	2.10	0.5165	0.2667	0.4576	0.752	−0.4061	1.48
	WHO	5	2.08	0.6106	0.3728	−1.0217	0.913	0.6871	2.00
POST_ Attention regulation	CoD	8	4.08	0.5560	0.3091	−0.3548	0.752	−0.6512	1.48
	WHO	5	3.37	0.9125	0.8326	0.1683	0.913	−1.1433	2.00
PRE_Emotional awareness	CoD	8	2.50	0.6928	0.4800	0.2887	0.752	−0.9250	1.48
	WHO	5	3.36	0.6542	0.4280	−2.1342	0.913	4.6790	2.00
POST_ Emotional awareness	CoD	8	4.42	0.5701	0.3250	−0.3154	0.752	−1.7276	1.48
	WHO	5	4.00	1.1489	1.3200	−1.0550	0.913	0.9669	2.00
PRE_Self-regulation	CoD	8	2.16	0.6400	0.4096	0.2161	0.752	−0.1049	1.48
	WHO	5	2.60	1.3062	1.7063	0.5861	0.913	−0.3385	2.00
POST_ Self-regulation	CoD	8	4.38	0.6124	0.3750	−0.7776	0.752	−0.0571	1.48
	WHO	5	3.70	1.0216	1.0437	−0.3473	0.913	0.4149	2.00
PRE_Body-Listening	CoD	8	2.04	1.3499	1.8222	−0.0175	0.752	−0.9724	1.48
	WHO	5	1.73	0.9269	0.8591	0.2371	0.913	−0.8817	2.00
POST_ Body-Listening	CoD	8	4.12	0.6657	0.4431	−0.1099	0.752	0.0280	1.48
	WHO	5	3.67	1.1058	1.2228	−0.6821	0.913	1.1194	2.00
PRE_Trusting	CoD	8	2.58	0.6117	0.3741	0.6851	0.752	−0.4693	1.48
	WHO	5	2.73	1.3650	1.8631	1.5223	0.913	2.5324	2.00
POST_Trusting	CoD	8	4.42	0.4961	0.2461	0.4799	0.752	−2.2481	1.48
	WHO	5	4.00	1.0277	1.0561	−1.2840	0.913	2.0199	2.00

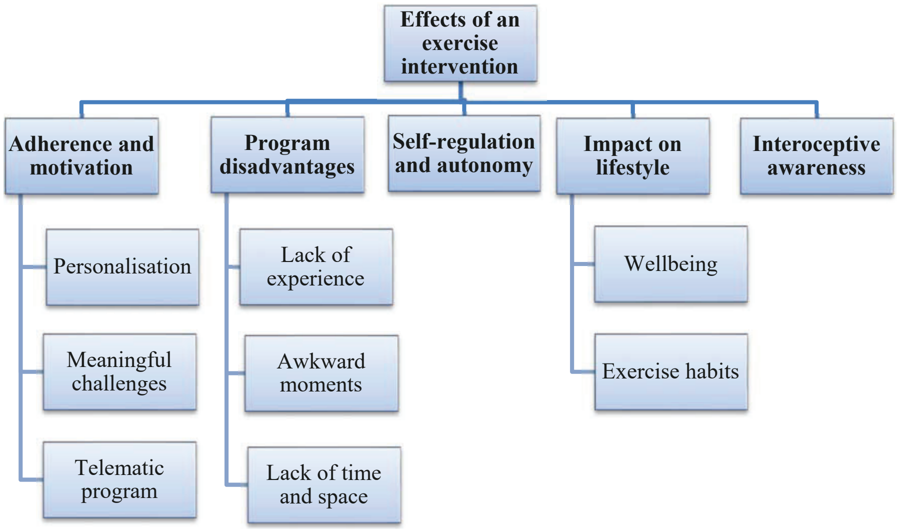

FIGURE 1
Themes and subthemes developed from the experiences of people participating in the exercise programs.

confirmed data saturation at n = 20 and revealed five themes based on the interview questions (see Figure 1).

Theme 1: Adherence and motivations during the program

Both groups concurred that being supervised by the personal trainer and receiving constant feedback facilitated their participation. Highlighting the personalization of the co-design was felt very motivating and helped to continue. They also appreciated the meaningful and novel challenges; "Not knowing what challenges the personal trainer was going to present to me next week kept me curious and motivated" (CoD8). A telematic exercise program was another widely reported benefit ""It was not necessary to go to a specific place; I could do the exercise at home during my free time" (WHO2).

Theme 2: Disadvantages of the program

Participants of the WHO group reported anxiety and stress due to their lack of experience exercising. "At the beginning, it was stressful because I am not used to it, and I did not feel fit" (NC5). As they principally exercised at home or work, they felt embarrassed when being observed by members of their families or co-workers; "I went to the bathroom to do some exercises so that my colleagues in the office could not see me" (CoD6). "During the Christmas holidays, I had my family at home, and I cared about what they could say when seeing me exercising" (NC3). The work schedule made participation difficult, and lack of time was the most reported problem in both groups; "I have little free time and find it difficult to combine exercise with family life. Physical activity is not a priority for me" (WHO4). Non-completers reported a lack of space or time to exercise; "Initially I felt very excited, but afterward it was difficult to get along and enjoy it due to my work schedule" (NC4). They dropped out of the study due to the program's lack of schedule flexibility and incompatibility; "It has been impossible for me to combine it with work and family issues" (NC6). Most participants of the CoD group, which also encountered the time barrier, succeeded in adapting to it by incorporating physical activity into their daily life in an autonomous way. "On the first day, I walked only for 30 min, but as the weeks went by, I increased the time as I felt better every day" (CoD6).

Theme 3: Self-regulation and autonomy

Participants of the CoD group adapted the exercise to their personal and environmental constraints and learnt how to self-regulate workload. "During holidays, I was not used to exercising, but this time I was able to do it because I knew the activities I could do" (CoD2) and "Being able to self-manage the activity's intensity and duration helped me do much more than I thought at first" (CoD2). They did not perceive the figure of the coach as essential due to the learnt autonomy "As time passed I was able to decide daily which activities were suitable and which not" (CoD1). The WHO group did not report self-regulation and autonomy capacities. "Although I was stressed by work, I did the series and repetitions of the strength workout I had to do" (WHO5). Non-completers found it challenging to decide on the exercise program and considered they were assuming too much responsibility; "It is impossible for me to self-regulate the intensity and the type of activity because I am always so tired that I would never do anything" (NC2).

Theme 4: Impact on lifestyle

The CoD group increased self-awareness and wellbeing: "I notice that when I walk, I get less tired, and I also notice fewer arrhythmias from the program's start" (CoD6). Many discussed their plans for exercising due to their wellbeing and trust "I feel good about myself and my body" (CoD5). Also, some of them have hired a personal trainer to continue exercising; "I have decided to continue with a personal trainer to try new different activities that I have always wanted to try" (CoD7). Other participants expressed having gained body awareness "I am now more aware of the physical activity I do in my daily life, and how I feel during and after doing it" (CoD2). "I am still exercising, incorporating my trainer's principles" (CoD3).

The WHO group also planned to change their habits by joining a gym where finding the required material. "I have decided to join a gym to access more material; it is easier for me to follow exercise routines" (WHO5). In line with the results of the questionnaires, "I have found that exercise helps reduce my anxiety and stress levels" (WHO3).

Theme 5: Interoceptive awareness

While the WHO group linked the intervention to their physical fitness, the CoD group linked it to multiple dimensions and a more general wellbeing state: "For me, health is more than a physical state. It is about being comfortable with yourself and knowing how to listen to your body to adapt to different contexts" (CoD7). Both groups stated that they had never been asked about their body state and sensations towards exercise. However, only the CoD group mentioned they had improved their interoceptive awareness; "I can recognize inflammatory states in my body based on stress, what I have eaten or what I have slept" (CoD5). "When I am nervous, I cannot trust my body signals" (WHO2).

Overall, 13 out of 20 participants were satisfied with the exercise program. However, only participants of the CoD group would recommend the program to other people; "Thanks to the constant dialogue with the personal trainer and trying different proposals, I have discovered the types of activities that work for me. Actually, I have incorporated it as a daily habit" (CoD3); while others would have preferred daily monitoring and comprehensive training planning; "I prefer to have a programmed exercise routine with technique instructions" (CoD7).

Discussion and conclusion

This study contrasts the effects on mental health and interoceptive awareness of co-designed exercise interventions and prescribed exercise programs based on the WHO recommendations for healthy adults. The co-designed intervention, aiming to guide participants from dependency to autonomy, promoted further mental health and interoceptive awareness, crucial aspects of cognitive and emotional wellbeing.

In alignment with previous research, the current study supports that exercise benefits mental health in adult population (Carek et al., 2011; Rebar et al., 2015; Bernstein and McNally, 2018). However, in this study, only participants of the CoD group reduced depression, anxiety and stress levels after the intervention. The duty to follow the program (i.e., "to take the exercise pill"), trying to comply strictly with WHO guidelines and following the exact doses contributed to increased anxiety and stress levels in some participants of the WHO group, These adverse effects have not been observed in participants performing new and challenging activities (González-Cutre et al., 2019).

In addition, only the CoD group expressed the wish to continue the intervention in the future. This can be explained by the positive affective valence reported during and after exercise by this group (Ekkekakis et al., 2011). In contrast, the emotional experience of the WHO group was not helping to introduce changes in their daily routine, as found in previous works (Kwan and Bryan, 2010; Antoniewicz and Brand, 2016). The pressure to follow a fixed exercise program, independently of daily constraints (e.g., holiday periods, family visits, amount of work), and the lack of novelty in the exercise routine may explain such results (Cao et al., 2021). As confirmed through the interviews, the five WHO participants who dropped out of the intervention reported getting overwhelmed when they could not comply with the prescribed routine and feel bored for doing the same type of exercise. Monotony seems a crucial factor contributing to low physical activity participation (Dalle Grave et al., 2011). Even active individuals engaged in the same exercise over time can reduce their motivation to the practice because of boredom (Lakicevic et al., 2020).

Enjoyment and interest seem determinant for ensuring long-term engagement (Argent et al., 2018) and adherence to exercise, leading ultimately to better health (Jekauc, 2015; Lakicevic et al., 2020). For example, performing similar physical activities in groups or virtual reality environments (e.g., exergaming approach) can create a distraction from negative thoughts related to exercise and encourage participation (Molina et al., 2014). Other authors propose an agreement between the athlete-trainer on goals and the selection of exercises to fit the athlete's needs, motivations, and abilities (Wackerhage and Schoenfeld, 2021). Some results have shown more outstanding fitness scores and affective responses when participants self-selected exercise conditions (Parfitt et al., 2006) or when designing their exercise program based on their previous knowledge instead of following a standardized exercise program (Papadakis et al., 2021).

Decisions to engage in regular physical activity are also influenced by participants' expectancies (Loehr et al., 2014). It is worth pointing out that the two CoD participants dropping out during the intervention expected to get involved in a standardized training program to become stronger. The literature refers to previous interventions, based on the SDT (Deci and Ryan, 2013), for increasing the motivation and adherence of patients to exercise treatments. Positive effects on adaptive motivational processes, quality of life and wellbeing have been reported (Duda et al., 2014). In fact, when participants self-paced or chose their mode of exercise, have more positive affective responses and autonomy than when they follow exercise prescriptions (Parfitt and Gledhill, 2004).

Although both (SDT practices and CoD intervention) consider participants' motivations and preferences, the CoD goes a bit further, proposing a change of roles: participants and professionals co-design and co-adapt continuously unique and personalized protocols to develop participants' self-knowledge and autonomy. That is, the initial program may evolve during the intervention due to the need of co-adapting to the multiple personal and environmental constraints affecting the process. For instance, a participant evolved from proposing home-based exercises to open-air activities in family and activities in nature (e.g., climbing mountains, trekking, etc.).

As confirmed through the interviews, the role of exercise co-designers developed in the CoD group self-knowledge, self-regulation, and autonomy. These potentially beneficial learning effects can also be associated with rewarding experiences (Fisher and Yarwood, 2008; Leckey, 2011). Being less dependent on the personal trainer, facilities and equipment, they could potentially create a larger adaptivity and guarantee a longer adherence to exercise. As they could choose the physical and social environments for exercising (e.g., in a park, in the mountains, with family, or friends), they could explore different exercise modalities, experience the most contextually adequate, and become more aware of their wellbeing and health.

It is worth pointing out that the commonly prescribed exercise for the adult population, converging on aerobic and strength programs and adhering to WHO recommendations, is based on oversimplified theoretical and methodological assumptions, as the possibility to transfer to individuals results obtained by comparing group data means (Balagué et al., 2020b). The network physiology of exercise conceptualizes the human organism as a complex adaptive system embedded and in constant interaction with social and policy factors (Bauman et al., 2012). Assuming there is no unique way to promote a healthy state (Sturmberg et al., 2019), some authors propose co-designing contextually sensitive, meaningful, motivating, and self-regulated exercise programs (Balagué et al., 2020a). However, as far as we know, few attempts have been made to contrast the emotional benefits of different exercise interventions (Hogan et al., 2015).

Concerning the interoceptive awareness effects, the light results obtained in the MAIA questionnaire by the WHO group (improving only in three of the eight scales), compared to the CoD group (seven of eight), can be explained by the lack of emphasis on the WHO intervention on interoceptive awareness and the aforementioned stressful experiences of participants. Stressed individuals show difficulties regulating emotional responses because they stopped trusting and listening to body signs (Price and Hooven, 2018). In contrast, the CoD group improved in seven of the eight scales and had fewer difficulties adapting the exercise type and characteristics to their personal and environmental constraints. An exciting outcome of performing novelty, motivating and challenging activities is the deep level of engagement which can lead to flow experiences (Swann et al., 2019; Montull et al., 2020), which increase autonomous motivation, reduces boredom, and relates to future involvement (Csikszentmihalyi, 2020).

Recent sports-related research has highlighted the need to develop early education programs to enhance interoceptive awareness (Montull et al., 2022). Our results show that a co-designed type of intervention may help to develop this relevant property. Unfortunately, no studies have tested the potential benefits of interoceptive awareness and self-knowledge on fitness states. We hypothesize a circular causality between both variables that need to be explored.

This research has some potential practical implications for future exercise interventions in adult population: (a) meaningful, motivating, and enjoyable activities may produce more psychological benefits than universal exercise recommendations, and lead to further exercise adherence, (b) initial exercise programs should be co-adapted to the changing personal and environmental constraints, not the other way around, (c) practitioners perceptions and interoceptive awareness should be developed to help on selecting adequately the type and characteristics of exercise and be the basis for workload adaptation. In turn, health professionals and personal coaches should: (a) be aware of the limitations of current exercise guidelines and be educated on co-designing instead of prescribing exercise, (b) lead practitioners from dependency to autonomy providing training criteria instead of exercise receipts, (c) contribute to the development of interoceptive awareness to prevent injuries, detect deleterious training effects (e.g., like overtraining) and promote a multidimensional fitness state (Almarcha et al., 2021).

It is recommendable to investigate the effects of co-designed exercise interventions on other populations like chronic patients and different age groups. In addition, a gender analysis, which was impossible to implement in this research due to the small number of participants, is also warranted.

It was expected to find more noticeable physiological effects of the intervention in the WHO group because participants were tested through cycle ergometers. While cycling was recommended in the aerobic training routines of the WHO group, the CoD group did not specifically practice cycling. Due to the low sample, no significant differences were found in cycling performance and physiological associates either inter or intra-groups. Further research is warranted to study the long-term effects of this type of intervention.

In conclusion, a co-designed exercise intervention was more effective for developing mental health, interoceptive awareness, autonomy, and exercise self-regulation in healthy adults than the prescription of an exercise program based on the universal recommendations of the WHO.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: doi: 10.6084/m9.figshare.19767163.v1.

Ethics statement

The studies involving human participants were reviewed and approved by Comité d'Ètica d'Investigacions Clíniques de l'Administració Esportiva de Catalunya (ref. 07/2015/CEICEGC). The patients/participants provided their written informed consent to participate in this study.

Author contributions

MA, NB, and CJ contributed to the conception and design of the study. MA and IG organized the database and wrote the first draft of the manuscript. MA performed the statistical analysis. MA and NB wrote the final manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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