How to merge observational and physiological data?
A case study of motor skills patterns and heart rate in exercise programs for adult women

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Título: ¿Cómo combinar datos observacionales y fisiológicos? Un estudio de caso de patrones de habilidades motoras y frecuencia cardíaca en programas de ejercicio para mujeres adultas.
Resumen: El presente estudio analiza las respuestas individuales y de grupo de la frecuencia cardiaca de mujeres adultas mientras realizan actividad física. El interés de este estudio recae en comparar como estas respuestas varían entre sesiones de ejercicio rutinario y sesiones que incluyen variedad de habilidades motrices. Participaron 67 mujeres adultas (edad 65.1 ± 11.7) usuarias de programas de actividad física municipales. Analizamos dos sesiones representativas: una estándar de los propios programas de actividad física que realizan y otra diseñada *ad hoc* con variedad de diversos tipos de habilidades y capacidades motrices. Utilizamos la metodología observacional para obtener datos categóricos de las habilidades motrices realizadas en cada sesión a partir del instrumento de observación OSMOS-in context. Los datos continuos obtenidos de la frecuencia cardíaca individual de cada participante se midieron mediante monitorización en cada sesión. El análisis conjunto de ambos tipos de datos, categóricos y continuos, se realizó mediante la aplicación de Cadenas Ocultas de Markov (HMM). Los resultados obtenidos consideramos que son bastante relevantes puesto que indican que la sesión que aporta mayor riqueza motriz no solo muestra una mayor adecuación cardíaca a la intensidad del ejercicio (según las recomendaciones del American College of Sports Medicine) sino una mayor variabilidad individual, incluso una mayor sincronización entre todas las participantes con respecto a la sesión estándar propia de los programas de actividad física que realizan asiduamente.
Palabras clave: Habilidades motrices; mujeres adultas; daos categóricos; datos continuos; Cadenas Ocultas de Markov.

Abstract: The present study analyzes individual and group heart rate responses in exercising adult women. The specific aim was to compare responses during routine workout sessions within a community exercise program with responses during a purpose-designed workout session targeting diverse motor skills. Sixty-seven adult women with a mean ± SD age of 65.1 ± 11.7 years participated in the study. Two representative sessions were analyzed: a standard workout session the women took at the local community center and an *ad hoc* session designed to build on a variety of motor skills and capabilities. Observational methodology was used to collect categorical data on motor skill performance during each session using the OSMOS-in context observation instrument. Continuous heart rate data were recorded for all participants during each session. A combined analysis of categorical and continuous data was undertaken using Hidden Markov Models. The results show that the session targeting a greater diversity of motor skills not only met the cardiovascular fitness recommendations of the American College of Sports Medicine, but resulted in greater individual variability and greater synchrony between participants than the routine session.
Key words: Motor skills; adult women; categorical data; continuous data; Hidden Markov Models.

Introduction

Studies analyzing the benefits of physical activity and factors influencing adherence to exercise programs targeting specific age groups have increased in recent years (Moreno-Murcia, Cervelló & Martínez-Camacho, 2007; Moreno-Murcia, Marcos-Pardo, Huescar, 2016; Puigarnau, Camerino, Castañer, Prat & Anguera, 2016). The health benefits of physical activity are well documented and the World Health Organization plays an important role in raising awareness of the importance of exercise among the general population. Through evidence-based recommendations from the World Health Organization, it also provides policy makers with guidance on how to design physical activity programs suited to the needs of different age groups according to aspects such as exercise frequency, duration, intensity, type, and amount. There is also strong evidence that rates of all-cause mortality are lower in more active adults. Although adults today are largely aware of the health benefits connected to exercising (Moreno-Murcia et al., 2016), an inverse relationship has

been reported between physical activity and age (Ansari & Lovell, 2009; Farid & Dabiran, 2012). Numerous barriers and deterrents have been identified in older adults reluctant to do exercise (Puigarnau et al., 2016) and women appear to be particularly affected by family and caring commitments (Jewson, Spittle & Casey, 2008) and general levels of fatigue (Malone, Barfield & Brasher, 2012).

The design of effective exercise programs is thus essential to help individuals overcome barriers and achieve a healthy lifestyle through physical activity (Moreno et al., 2016). In Spain, numerous exercise programs targeting adult women are offered by both private and public bodies. These programs typically feature exercises designed to strengthen key conditioning components such as aerobic fitness, muscle strength, flexibility, agility, and balance. Based on recommendations of the American Heart Association (AHA) and the American College of Sports Medicine (ACSM), cardiovascular exercise needs in adults can be met by at least 30-60 minutes of moderate-intensity exercise or 20-60 minutes of vigorous-intensity exercise a week (Nelson, Rejeski, Blair, Duncan, Judge, King & Castaneda-Sceppa, 2007).

Previous work by our group analyzing different exercise programs for adults suggests that while the programs appeared to be varied in content, they actually offered very lit-

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tle variety in terms of motor skills, suggesting a focus on quantity rather than quality (Castañer & Saüch, 2013; Castañer, Barreira, Camerino, Fernandes, Anguera & Hileno, 2017). In general, we observed that motor skill sequences within datasets generated using a systematic observational methodology showed little variation from one program to the next. Furthermore, although the programs generally met the demands for moderate-to-vigorous physical activity they did not enhance motor skill diversity. Exercise intensity has been analyzed extensively in sports sciences and information on differences in cardiovascular demands can help to tailor training needs to the age and/or sex of athletes (e.g. Vaquera, Mielgo-Ayuso, Calleja-González & Leicht, 2016). Exercise intensity is typically analyzed by measuring heart rate (HR), which, as a quantitative measure can provide information on the quantity (e.g., intensity) of exercise, but not on its quality (e.g., diversity). The ACSM highlights the importance of distinguishing between the quantity and quality of exercise (Garber, Blissmer, Deschenes, Flanklin, Lamonte, Lee,… Swain, 2011), claiming that *"behaviorally based exercise interventions, the use of behavior change strategies, supervision by an experienced fitness instructor, and exercise that is pleasant and enjoyable can improve adoption and adherence to prescribed exercise programs"*. This claim is consistent with findings from a previous study by our group (Puigarnau et al., 2016).

The aim of this study was to compare motor skills used by adult women in standard physical activity sessions compared with sessions specifically designed to build on a diversity of motor skills while meeting the needs for moderate to vigorous physical activity as defined by the ACSM (2014). As part of a larger challenge to integrate categorical and continuous data, we employed a mixed methods design in which we analyzed associations between quantitative data (heart rate) and categorical data (motor skill patterns).

Method

We employed observational methodology (Anguera & Hernández-Mendo, 2014; 2015; Sánchez-Algarra & Anguera, 2013), which has proven to be a powerful tool for analyzing physical activity benefits (Warburton, Nicol & Bredin, 2006) and motor skills (Castañer, Camerino, Parés, & Landry, 2011). A portable heart rate (HR) monitoring device was used for dynamic heart rate measurements. Categorical (observational) and continuous (HR) data were analyzed simultaneously using a Hidden Markov Model (HMM). All the data extraction, pre-processing and HMM analyses were performed using a custom MATLAB program (The Mathworks, Boston, MA).

Participants

Sixty-seven adult women with a mean ± SD age of 65.1 ± 11.7 years participated in the study. The sample consisted of five homogeneous groups following similar exercise programs. For the study, we analyzed two representative

workouts: one conventional workout (VAL1, taken by 67 participants) and another *ad hoc* workout designed to build on a diversity of motor skills (VAL2, taken by 64 of the participants). All participants signed an informed consent form and the study was approved by the ethics committee at the University of Lleida (code CEIC-1450).

Procedure

Types of sessions

In the first phase of the study, which lasted two weeks, each group was video-recorded while performing a standard 50-minute workout session at a local community sports center (VAL1 protocol). This session basically consisted of functional segmental mobility exercises and aerobic exercises involving walking. During the third week, the same groups were video-recorded again following the specially designed workout session (VAL2 protocol), which also lasted 50 minutes. This second session was specifically designed to include a wide range of motor skills ordered in a sequential protocol that allowed adaptation of HR to exercise intensity and also included adequate HR recovery periods. The VAL2 session was structured as follows:

a) An initial stage of 8-12 minutes targeting a variety of locomotor skills, such as walking forwards, backwards, sideways, etc., combined with conditioning components such as aerobic endurance, stretch, power, and speed.
b) A second 20-minute stage featuring similar motor skill and conditioning tasks in addition to manipulation tasks involving objects and interaction with other participants.
c) A third and final 15-minute stage targeting stability, manipulation, and conditioning.

The overall session was designed to promote different types of interaction between participants and the general approach was basically playful and recreational (Garber et al., 2011). During each session, the participants' HR was monitored continuously using a wireless system.

Instruments

Observation instrument

The video-recordings of the sessions were analyzed using the OSMOS-in context observation instrument, which is an adaptation of the original OSMOS instrument (Castañer et al., 2009) that has been used to analyze motor skill patterns in exercise programs and individual use of motor skills in team sports (Castañer, Barreira, Camerino, Canton & Hileno, 2016; Castañer et al., 2017; Castañer, Camerino, Landry & Parés, 2016). It comprises seven broad criteria (motor profile, interpersonal interaction, stability skills, locomotor skills, manipulation skills, physical capabilities) each one expanded to build 53 exhaustive, mutually exclusive categories. The criteria and categories are summarized in Table 1.

Table 1. OSMOS-in context: System of Observation of Motor Skills in Context

CRITERIA	CATEGORIES/ CODE
Motor profile	Utilitarian (U)
	Competitive (C)
	Recreational (R)
	Therapeutic (T)
	Utilitarian & competitive (UC)
	Utilitarian & recreational (UR)
	Utilitarian & therapeutic (UT)
	Recreational & competitive (RC)
	Therapeutic & competitive (TC)
	Recreational & therapeutic (RT)
	Combination of motor profiles (OMP)
Interpersonal interaction	Individual work (INdv)
	Dyadic interaction (IDyd)
	Micro group interaction (Imic)
	Macro group interaction (Imac)
	Combination of Interaction types (CI)
Stability skills	Support stability (SS)
	Elevation stability (ES)
	Axial Stability (AS)
	Combination of stabilities (COS)
Locomotor skills	Propulsion-stop locomotion (Lp)
	Sequential rebalance locomotion (Ls)
	Simultaneous coordinated locomotion (Lc)
	Combination of locomotor skills (COL)
Manipulation skills	Impact manipulation (Mi)
	Directing manipulation (MD)
	Combination of manipulation skills (COM)
Physical capabilities	Aerobic endurance (AERO); Reaction speed (RSPD); Strength (STRG); Stretch (STCH); Muscular potency (PO); Agility (AG) Aerobic + reaction speed (AERE); Aerobic + strength (AESTG); Aerobic + stretch (EAST); Aerobic + potency (AEPO); Aerobic + agility (AEAG); Reaction speed + strength (RESTG); Reaction speed + stretch (REST): Reaction speed + potency (REPO); reaction speed + agility (REAG); Stretch + strength (STSTG); Stretch + potency (STOP); Stretch + agility (STAG); Strength + potency (STGPO); Strength + agility (STGAG); Potency + agility (POAG); Combination of physical capabilities (CPC)
Cognitive skills	Imitation (IMI)
	Problem resolution (PROB)
	Memory (MEMO)
	Combination of cognitive skills (COCO)

Recording instrument

The exercise sessions were coded using the free software program LINCE (v.1.2.1) (Gabin, Camerino, Anguera, & Castañer, 2012; Hernández-Mendo, Castellano, Camerino, Jonsson, Blanco-Villaseñor... Anguera, 2014), which was also used for the data quality check. The sessions were coded by two experts in exercise programs and the inter-observer reliability was .87.

HR monitoring

HR data were collected using a Polar Team 2.1 monitoring device worn by all participants during each workout session. At the beginning of each session, the transmitters were placed around the participants' chest, just under the chest muscles, and were synchronously activated and disabled, thus enabling the simultaneous tracking-and subsequent comparison-of real-time HR and percentages of maximum HR (HRmax). The data were acquired at a sampling frequency of 1 Hz.

Data analysis

In order to simultaneously describe the HR time series and observational motor skill categories, we performed a hybrid analysis using a Hidden Markov Model (HMM). Such models have been previously used in many different areas, such as speech recognition (Rabiner, 1989), biological sequence analysis (Eddy, 2004), and physical activity recognition (Lester, Choudhury & Borriello 2006) and constitute a flexible approach for describing sequential data combining categorical and numerical variables. HMMs describe the dynamic patterns between a state (motor skills in our case) and a measured variable (participant HR). States were defined as groups of concurrent categories from the OSMOS-in context instrument and the output variables were the instantaneous HRs recorded for the participants. A HMM was fitted for each participant and workout session to investigate the dynamics between the workout session and individual cardiac responses.

Results

The HMM approach allows an independent analysis of states, measured variables, and the correlation between these states and variables. We focused on the comparison between VAL1 and VAL2 for each of these aspects. The main findings are summarized in the sections below. All values shown are *mean ± SD* unless indicated otherwise. Again, unless otherwise indicated, statistical comparisons between VAL1 and VAL2 were performed using a two-sample t-test at a 95% significance level.

Diversity of motor skills

The diversity or "richness" of motor skills in the VAL1 and VAL2 protocols was quantified by two magnitudes extracted from the state dynamics of the HMMs.
Number of motor skill configurations (number of independent HMM states). VAL2 had a significantly higher number of motor skills configurations (19.62 ± 1.35 vs. 12.75 ± 1.6 for VAL1, *p* < .01) and can thus be considered richer in terms of coordination and cognitive demands.
Number of different OSMOS-in context categories within the configurations (diversity of states, motor skill richness). VAL2 al-

so had a higher number of OSMOS-in context categories for each criterion in the instrument (29.13 ± 0.55 vs. 20.5 ± 0.38 for VAL1*, p* < .001), again indicating greater motor skill richness.

Cardiac response

HR variability. No significant differences were observed for mean HR between participants in the VAL1 and VAL2 sessions (108 ± 2.32 bpm vs. 111.4 ± 2.1 bpm). However, mean ± SD individual HR variability was significantly higher (p < .001) for VAL2 (14.75 ± 0.59 bpm) than for VAL1 (11.32 ± 0.72 bpm).

Inter-subject synchrony. HR synchrony between participants was measured by maximum cross-correlation between pairs of HR time series for the sample. On average, there was a stronger correlation between cardiac responses for VAL2 than for VAL1 (0.7584 ± 0.008 vs. 0.7086±0.012, p < .001), indicating greater synchronization of motor skill responses during the specially designed protocol.

Figures 1 and 2 show the changes in cardiac responses and motor skill sequences over a representative VAL1 and VAL2 workout. The lower HR variability and greater synchrony in the VAL1 session (Figures 1 and 2, lower panels) reflect the above results. The top panels show the changes in HMM states during the two sessions.
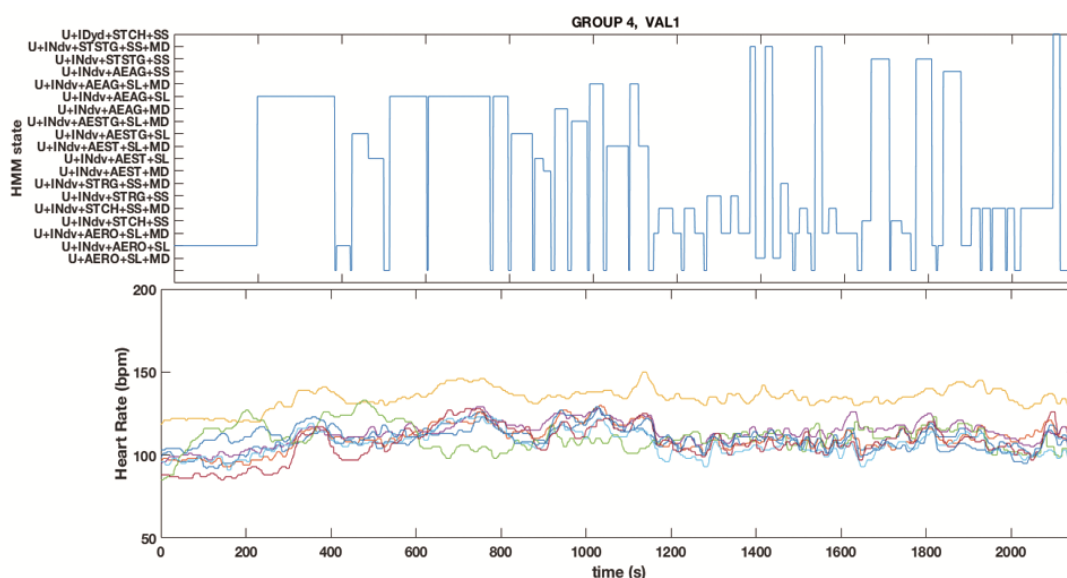

Figure 1. Changes in motor skill sequences corresponding to HMM states (upper panel) with corresponding changes in cardiac responses (lower panel) during a representative VAL1 session.
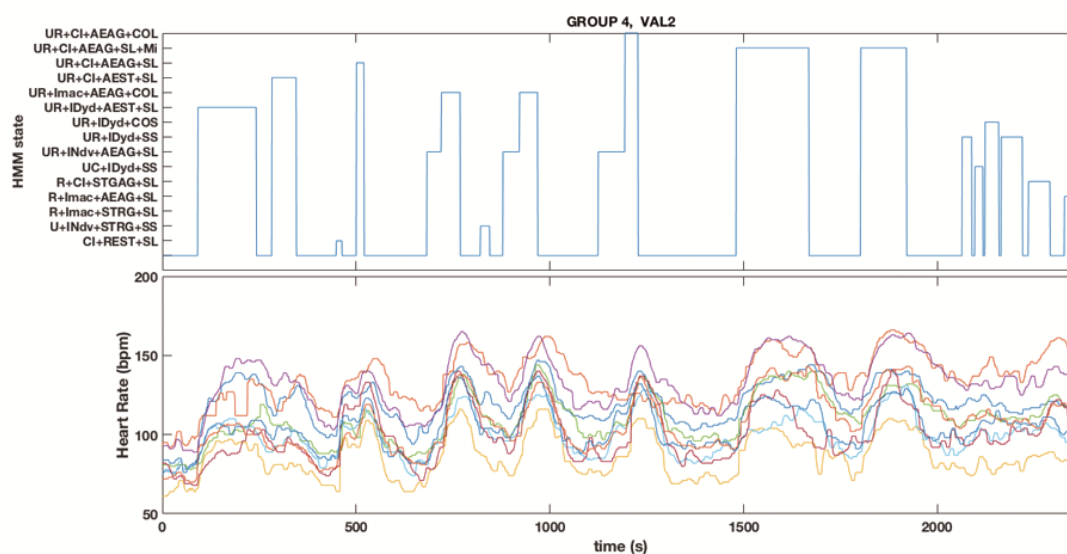

Figure 2. Dynamical evolution of cardiac responses (lower) and motor skill sequences (upper) during a representative VAL2 session. Upper panel represents HMM states corresponding to the different sequences of motor skills and lower shows the time evolution of the individual heart rate responses of the participants in the session.

Cross-correlation analysis between motor skills and cardiac response

In order to quantify the synchrony between motor skills and cardiac response, we estimated the sample cross-correlation function (CCR) between HR time series and dynamic HMM states. The significance of the CCR function at each time lag was established using 95% confidence intervals. The lag at the maximum CCR was used to determine the time lag between motor skill configurations and cardiac response for each participant and session.

The maximum CCR value did not differ significantly between the two protocols (0.48 ± 0.017 for VAL1 vs. 0.52 ± 0.016 for VAL2; $p = 0.19$), although the median lag between the motor skill configurations and cardiac response was significantly higher in VAL1 than in VAL2 ($p < .001$, Wilcoxon rank sum test).

A more detailed analysis of the distribution of time lags allowed us to classify participants into two groups based on cardiac response: participants with time lags under 60 seconds, i.e., individuals with exercise-responsive cardiac dynamics, and participants with time lags of 60 seconds or more, i.e., participants with a slower cardiac response in terms of both activation and recovery. In VAL1, 69.6% of the participants had time lags under 60 seconds, compared with 90.6% in VAL2. On analyzing these individuals only, we observed no significant differences between the VAL1 and VAL2 protocols (27.74 ± 1.55 s vs. 31.42 ± 1.33 s, $p < .001$, Wilcoxon rank-sum test).

Figure 3 shows the distribution of participants according to time lags with respect to HMM states. Note the considerably higher number of participants with lags of 60 seconds or longer in VAL1 (top panel).
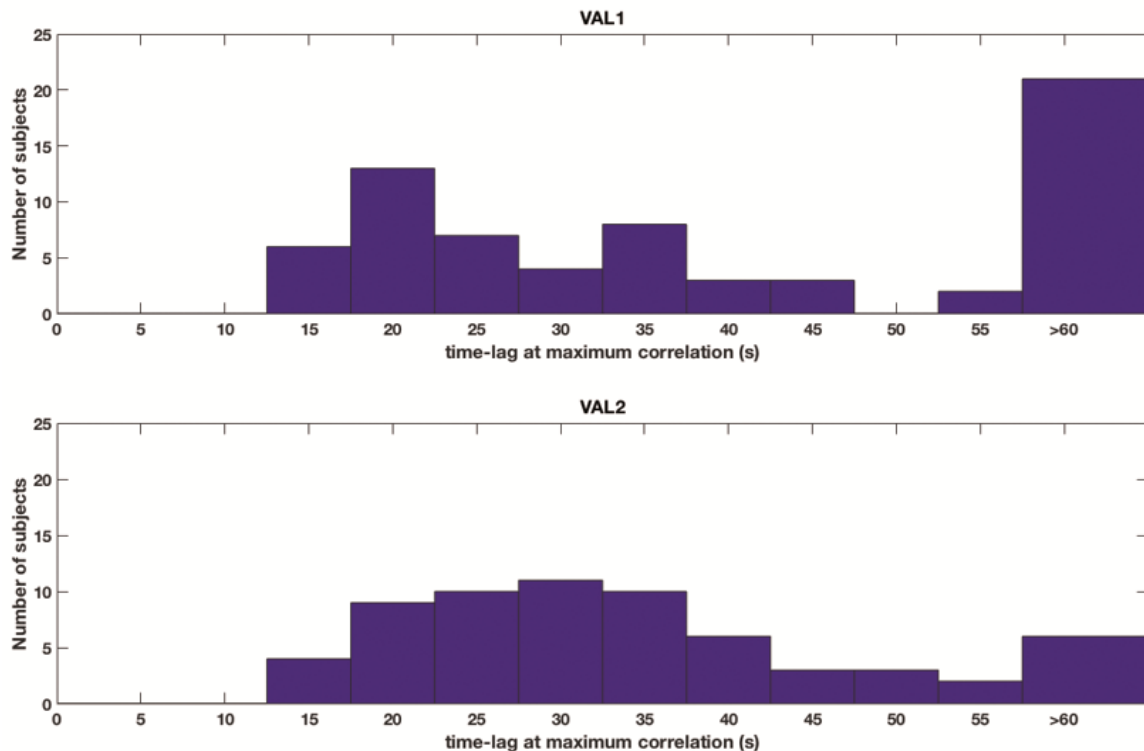

Figure 3. Distribution of time lags between cardiac response and motor skill states in VAL1 (upper panel) and VAL2 (lower panel) protocols.

Discussion

Our findings show that standard recreational fitness programs for adult women prioritize functional exercises based on repetitive actions aimed at improving strength, cardiovascular endurance, flexibility, and balance (ACSM, 2014). In our opinion, this functional approach is limited as it focuses excessively on conditioning. In this study, we specifically focused on the relevance of the "richness of body motor components" (Castañer et al, 2009; 2011) by designing an exercise program that merged diverse motor skill tasks (lo-

comotion, stability, and manipulation) with perceptual and conditioning tasks.

In the rest of this section, we discuss our main results and their relevance.

Routine versus varied motor skill patterns

Our results show that the purpose-designed VAL2 protocol offered a greater variety of motor skill patterns than the VAL1 sessions. This observation of greater variety is in line with emerging findings (e.g., Zourdos et al., 2016) that

suggest that the use of varied exercise stimuli produces more physiological and motor skill benefits than repetitive stimuli organized in long blocks of activity. In other words, the inclusion of varied motor stimuli in exercise programs may not only improve physical performance but also help to enhance motor skill development and conditioning abilities.

HR variability is higher in exercise sessions with a greater variation of motor skill patterns

Although mean HR did not vary significantly between VAL1 and VAL2 participants, HR variability, a well-established indicator of cardiovascular health (Task Force, 1996; Soares-Miranda et al., 2014) was higher in VAL2. While the mean HR values for VAL1 and VAL2 show that both types of sessions are sufficient to guarantee the moderate to vigorous intensity levels recommended by the ACSM (2014), the HR curves in VAL1 were flatter than in VAL2 in all cases (Figures 1 and 2, bottom panels). Our findings thus suggest that rich, varied exercise sessions, combining different motor skill tasks, favor cardiovascular health.

Exercise sessions with varied motor skill tasks increase inter-subject synchrony

Our results show a higher synchrony between participants in sessions featuring a greater variety of motor skill patterns. In other words, even though the content of the VAL2 session was more varied, cardiac responses were more similar within each group than when they participated in the more repetitive VAL1 sessions. In our opinion, this is a very interesting finding as it shows that a program targeting the development of motor skills resulted in a greater synchronization of effort among participants than more individual-centered, repetitive sessions. This observation supports previous reports that more enriching physical work favors interactions between participants (Kamegaya, Araki, Kigure & Yamaguchi, 2014; Puigarnau, Camerino, Hileno & Castañer, 2013). It would therefore appear that the inclusion of fun, interactive activities in "rich" exercise programs would favor synchronization and collaboration.

Sessions with varied motor skill tasks are associated with better time lags between exercise workloads and cardiac response

Better time lags between different exercise workloads and HR responses were observed in the VAL2 protocol, suggesting that workout sessions containing more diverse motor skill tasks favor cardiovascular responses. A similar benefit was also observed for the recovery phases. The proportion of participants with time lags of 60 seconds or higher was considerably higher in the traditional workout sessions analyzed.

Physical activity is inextricably linked to health and quality of life (Paxton, Motl, Aylward & Nigg 2010; Sumpter, García & Pozo, 2015) and as such the promotion of sport and exercise among the general population constitutes a public health priority that should include the engagement of professionals, organizations, and agencies responsible for creating environments conducive to the practice of physical activity (Pilkington, Powell & Davis, 2016). However, while environment is an important factor in any physical activity program, so too is content. The results of our study suggest that those responsible for designing the content of targeted training programs should pay more attention to the quality of these programs. We believe that programs that favor interaction between participants and build on a rich variety of motor skills (Castañer, Camerio, 2016; Puigarnau et al., 2016) will ultimately favor adherence and bring greater health benefits.

Conclusions

The findings of this study strongly suggest that exercise programs targeting adults should aim to build on a diversity of motor skills. The variety of tasks in the VAL2 protocol meant that the participants worked on a diverse range of motor skills as evidenced by the data obtained using the ad hoc observation instrument OSMOS-in context. We have shown that this tool is suitable for observing motor skill behavior and PA profiles, in the context of exercise programs. In conclusion, exercise protocols with a richer variety of motor skills are more likely to favor participant interaction and engagement, and improve HR variability and cardiac response. Considering that there is abundant scientific evidence showing that physical activity protects against age-related cognitive decay, and that maintenance of cognitive function is directly linked to a better lifestyle, it would seem only logical to include cognitive tasks in the repertoire of activities that comprise a rich exercise program. This of course represents a new challenge in terms of applying suitable methodological approaches to integrate the different types of data involved.

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