Development of a Web-based Program for Personalized Physical Exercise for Older Adults

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Abstract: Information technologies support personalized strategies to promote the effectiveness of physical exercise programs. The study reported by this paper developed a web-based program for personalised physical exercise for community dwelling older adults. Considering the Medical Research Council framework for developing and evaluating complex interventions, the paper reports the results of the development phase, which is the first phase of this framework. The development phase included the identification of the existing evidence, the identification of the developing theory, and the modelling of the intervention. The developed program and respective web-based application integrate the inherent complexity of physical exercise programs and allow the definition of personalized prescriptions considering a diverse range of factors (i.e., frequency, intensity, time, type, volume, and progression) recommended by international guidelines.

1 BACKGROUND

Accidental falls and fall-related injuries are major problems among older adults and put them at higher risk of functional limitations, disabilities, and even death (Kannus, Sievänen, Palvanen, Järvinen & Parkkari, 2005). Specifically, in the European Union, between 2010 and 2012, there were, approximately, 3,750,000 admissions to hospitals related to falls each year (Turner, Kisser & Rogmans, 2015).

The risk of falls is related to the environment (e.g., architectural barriers, such as poor lighting or slippery surfaces), behaviours (e.g., nutritional habits or consumption of alcohol and tobacco), and limitations of physical performance, such as poor muscle strength and balance, or functional, cognitive, and sensory impairment (Turner et al., 2015). Since physical activity contributes to increase or maintain physical performance, several guidelines (e.g., (Ferguson, 2014; Committee PAGA, 2018; US Department of Health and Human Services, 2018; World Health Organization, 2020; Izquierdo et al., 2021)) establish recommendations for exercises that increase endurance and flexibility, strengthen muscles, and improve balance, aiming to prevent falls and promote a healthy living (Vozzi et al., 2022).

The remote control offered by information technologies, namely web-based or mobile applications and ambient assisted living systems (Queirós et al., 2015), constitute a potential facilitator for the dissemination of physical exercise programs (Vozzi et al., 2022).

Since the effectiveness of exercise programs at distance for older adults requires further research, this

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paper reports on the development of a web-based program for personalized physical exercise for community dwelling older adults. This development was performed in the context of the project Built Environments for an Active, Safe, and Healthy Life (Ambientes Construídos para uma Vida Ativa, Segura e Saudável - ACTIVAS).

2 METHODS

In 2000, the Medical Research Council (MRC) introduced a framework to guide the development and evaluation of complex interventions (Medical Research Council, 2000), being complex interventions defined as interventions with more than one component (e.g., what practitioners and patients should do).

The 2000 version of the MRC framework had some limitations due to its similarity to those used to guide the development of drugs. Consequently, a revised version was published in 2008 (Craig et al., 2008), which proposed four phases with no linear or cyclic order:

- Development – systematization of the theoretical understanding of the intervention, the outcomes that are expected, and the specific approaches to achieve these outcomes considering the current scientific evidence.
- Feasibility and pilot – determination of acceptability, compliance, delivery of the intervention, recruitment, and retention, as well as unexpected side effects not predicted during the development phase.
- Evaluation – assessment of the effectiveness of the intervention, namely by conducting randomized controlled trials.
- Implementation – Dissemination of the intervention and its results to be reliably replicated in uncontrolled settings over the long term.

This paper reports on the development phase of a web-based program for personalized physical exercise for community dwelling older adults. According to the MRC framework, the development phase was decomposed into three steps:

- Identifying the existing evidence – a literature review was performed, which included existing guidelines of recommended physical activity (e.g., (Ferguson, 2014; Committee PAGA, 2018; US Department of Health and Human Services, 2018; World Health Organization, 2020; Izquierdo et al., 2021)) and systematic reviews related to the implementation of physical activity and physical exercise programs (e.g., (Sherrington et al., 2020; Di Lorito et al., 2021; Rodrigues, Domingos, Monteiro & Morouço, 2022)).
- Identifying the developing theory – considering the results of the literature review, a schematic model of the intervention was prepared to systematize target behaviour, intervention components, and long-term outcomes.
- Modelling the intervention – the responsibilities of the practitioner and the actions of the participant were identified, as well as the nature of the exercises and the methods of organizing and delivering these exercises. Moreover, practicalities and the concrete structure of the intervention were developed and refined, including the information models of the physical exercise program and exercises, interfaces of the proposed web-based application, and a preliminary exercise set.

Modelling the intervention might include studies to progressively refine the design before embarking on a full-scale evaluation (Craig et al., 2008). Therefore, in the near future, practitioners and potential participants will be involved in a focus group and a usability study to assess respectively the practitioner and participant instructions and the adequacy of the proposed practitioner and participant user interfaces to identify and surpass potential drawbacks.

3 RESULTS

This section reports the results of the three steps of the MRC development phase, as stated in the Methods section.

3.1 Identifying the Existing Evidence

Although physical activity has been identified as a protective factor against physical and cognitive decline, cardiorespiratory, metabolic and immune systems' dysregulation, mental illness and falls (Committee PAGA, 2018), a large percentage of older adults have a sedentary behaviour defined as spending more than 5.5h per day sitting at work or driving, sitting at home while watching TV, reading, eating, or sitting at a desk (Remón, Díaz-Benito, Beatty & Lozano, 2020).

Physical activity is defined as any activity that incorporates bodily movement produced by muscle

contraction and that requires an increase in energy expenditure relative to the resting condition (Caspersen, Powell & Christenson, 1985; Ferguson, 2014). In turn, physical exercise is defined as a subtype of physical activity, which is planned, structured, repetitive, and purposeful to preserve or improve skill-related components of physical fitness (Caspersen et al., 1985; Ferguson, 2014).

Physical exercise can be performed in several settings, from clinical to home settings, supervised or not, in an individual or group format (US Department of Health and Human Services, 2018), being the most important aspect, the motivation of the participant. In this sense, physical exercise performed by a group has been recommended as a facilitator of adherence by older adults when compared to exercise performed alone at home (Di Lorito et al., 2021).

To guarantee the various aspects to consider when prescribing an exercise program, the American College of Sports Medicine (ACSM) proposed the Frequency, Intensity, Time, Type, Volume, and Progression (FITT-VP) principles (Ferguson, 2014; Bushman, 2018). Specifically, (i) frequency defines how often are the physical exercises done each week (Bushman, 2018), (ii) intensity defines how hard is the physical exercise (e.g., very light, light, moderate or vigorous) (Bushman, 2018), (iii) time represents the duration of an exercise modality within a session, as well as, the total duration of an physical exercise program, (iv) type defines the modality of a physical exercise, being an exercise modality a category that encompasses exercises with a common primary goal related to a specific health or skill component of physical fitness (Caspersen et al., 1985), (v) volume represents the total amount of physical exercise (Bushman, 2018), and (vi) progression characterizes how the physical exercise program is advanced (Bushman, 2018).

Considering the type of exercise or modalities, mobility exercises refer to an exercise set that explores the maximum range of motion available in a joint (Kisner & Colby, 2009). They aim to preserve or improve the range of motion to allow a body segment to have more freedom of movement to perform functional tasks (Kisner & Colby, 2009). These exercises may include movements to improve the range of motion in a specific joint, as well as to promote the participant's ability to transfer from one body position to another (e.g., lying to sitting or sitting to standing).

In turn, resistance exercises require muscle contraction against an external resistance or weight, which can be the body itself (or just part of it) to increase muscle mass and strength (American College of Sports Medicine, 2009; Rodrigues et al., 2022). There are different types of resistance exercises including muscle strength (i.e., to improve the muscle´s ability to exert force), endurance (i.e., to improve the ability of muscles to exert external force for many repetitions), and power (i.e., the ability to exert muscle force at high speed) (Caspersen et al., 1985; Ferguson, 2014; Rodrigues et al., 2022).

Moreover, balance exercises aim to assure the ability to maintain the equilibrium, while stationary (i.e., static balance) or moving (i.e., dynamic balance), while flexibility exercises play an important role in functional mobility, as they encompass movements/postures to improve or maintain the extensibility of soft tissues that cross or surround the joints.

Finally, aerobic exercises (American College of Sports Medicine, 2009; Ferguson, 2014) aim to improve cardiovascular endurance, and should incorporate exercises such as walking, running, cycling, and dancing (Ferguson, 2014; US Department of Health and Human Services, 2018) to increase heart rate and optimize the venous return.

A recent systematic review comprising more than one hundred studies and twenty-five thousand participants showed that general physical activity reduces the rate of falls by 23% when compared with control and that this ratio increases up to 28% when multiple modalities of exercise are included (Sherrington et al., 2020).

Independently of the exercise modalities, warm-up and cool-down exercises should be performed before and after the conditioning phase, respectively, allowing a gradual increase in heart and respiratory rate and facilitating the return of the participant to baseline activity, respectively (US Department of Health and Human Services, 2018).

3.2 Identifying the Developing Theory

Figure 1 presents a schematic model of the intervention supported by the web-based program for personalized physical exercise for older adults. This model highlights target behaviour, intervention components, and long-term outcomes.

The intervention aims to promote the practice of physical exercise and has four main components:

- Initial functional assessment – the intervention begins with the initial functional assessment of the participant performed by the practitioner, which is essential to define a personalized exercise program.
- Prescription – the exercise program is materialized in a variable number of exercises

that must be structured according to a specific prescription protocol. This prescription is supported by the practitioner interface of the web-based application. In addition to the type and number of exercises, the prescription also comprises additional parameters related to frequency, intensity, time or duration, volume, and progression of the exercises.

- Implementation – the exercise program is performed remotely by the participant with the support of the web-based application. This presents the exercises and respective instructions and gathers the participant feedback.

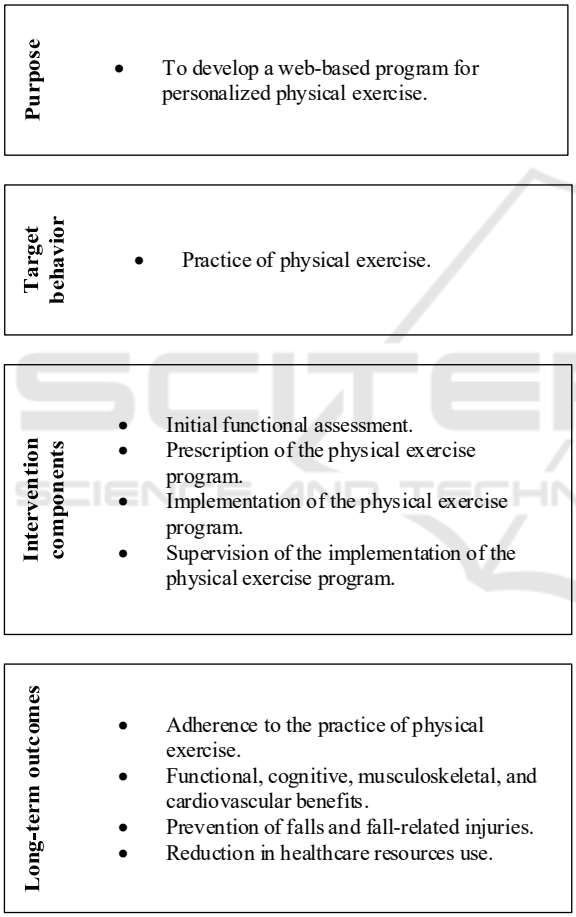

Figure 1: Schematic model of the physical exercise intervention.

- Supervision – periodically, the practitioner performs an assessment of the participant and an analysis of the respective progression to determine if it is necessary to adjust the initial prescription.

Considering the long-term outcomes, the web-based physical exercise program aims to promote adherence to the practice of physical exercise by older adults. This adherence not only promotes functional, cognitive, musculoskeletal, and cardiovascular benefits but also helps to prevent falls and fall-related injuries (Fragala et al., 2019). This means that long-term outcomes include functional, cognitive, musculoskeletal, and cardiovascular benefits, as well as falls and fall-related injuries prevention, which, consequently, might reduce the use of healthcare resources.

3.3 Modelling the Intervention

Based on the existing evidence and the identified developing theory, information models for both the physical exercise program and the individual exercises that constitute it were defined. These supported the development of the web-based application, both in terms of the practitioner and the participant interaction. Moreover, a preliminary exercise set was created.

3.3.1 Modelling the Exercise Program

A physical exercise program is composed by a variable number of exercises that must be structured according to a specific prescription protocol, which, as already mentioned, defines the frequency, intensity, time, type, volume, and progression of the exercises.

The program duration together with frequency (i.e., the number of sessions per week) determines the total number of sessions. In turn, the sessions are composed of sets of exercises, although a period of rest is recommended between two consecutive sets of exercises.

Moreover, there are different types of exercises (i.e., modalities). Independently of the respective modality, each exercise might be repeated and progressed as appropriate to each participant.

The progression of exercise might be operationalized by manipulating diverse parameters, such as speed, load, type of contraction (e.g., isotonic, or isometric), type of resistance (e.g., body weight or external resistance), base of support (e.g., feet position) or a combination of these, considering the specificities of the different exercise modalities and the characteristics of the individuals. However, having too many parameters to characterize each physical exercise makes the prescribing process difficult, time-consuming, and error prone. To overcome this drawback, the proposed information

exercise model defines that each exercise has different difficulty levels, which abstracts the configuration parameters. For instance, Table 1 illustrates the use of speed, surface incline, body weight, additional weight, coordination element, and feet position to distinguish difficulty levels of an aerobic exercise (i.e., walking), a resistance exercise (i.e., hip abductors strengthening), and a balance exercise (i.e., calf raises).

Finally, each exercise difficulty level must have instructions (i.e., both instructions to the practitioner and participant).

Figures 2 and 3 formalize the information models of both the program (Figure 2) and the physical exercise (Figure 3).

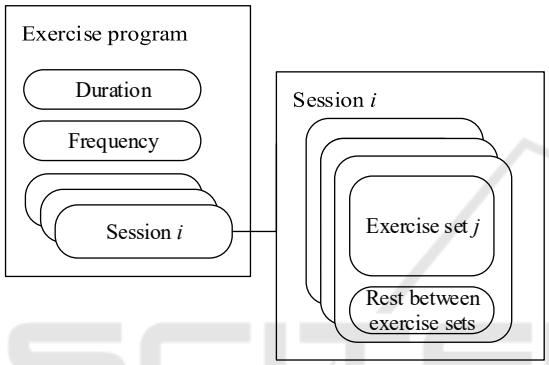

Figure 2: Information model of the physical exercise program.

The physical exercise program (Figure 2) has a duration and a frequency, which are translated into sessions 1 to *i*. Each session has 1 to *j* exercise sets, and after each exercise set, there might be a rest period.

In turn, each exercise (Figure 3) is associated with one of the following modalities, according to its characteristics: (i) mobility training; (ii) resistance training; (iii) balance training; (iv) flexibility training; and (v) aerobic training. Moreover, a particular exercise might be repeated (i.e., 1 to *k* repetitions) and has 1 to *l* difficulty levels.

Finally, for each difficulty level of each exercise, instructions need to be prepared for both the practitioner and participant, which contain textual, graphical, and video information.

The practitioner's instructions include:

- Joint name (only for exercises involving more than one joint).
- Starting position (in the case of exercises performed in a standing position, it should be specified whether the exercise should be done with or without hand support).
- Inclusion of progression parameters as mentioned before, when applicable.
- Description of the movements with reference to the joints involved (if necessary).

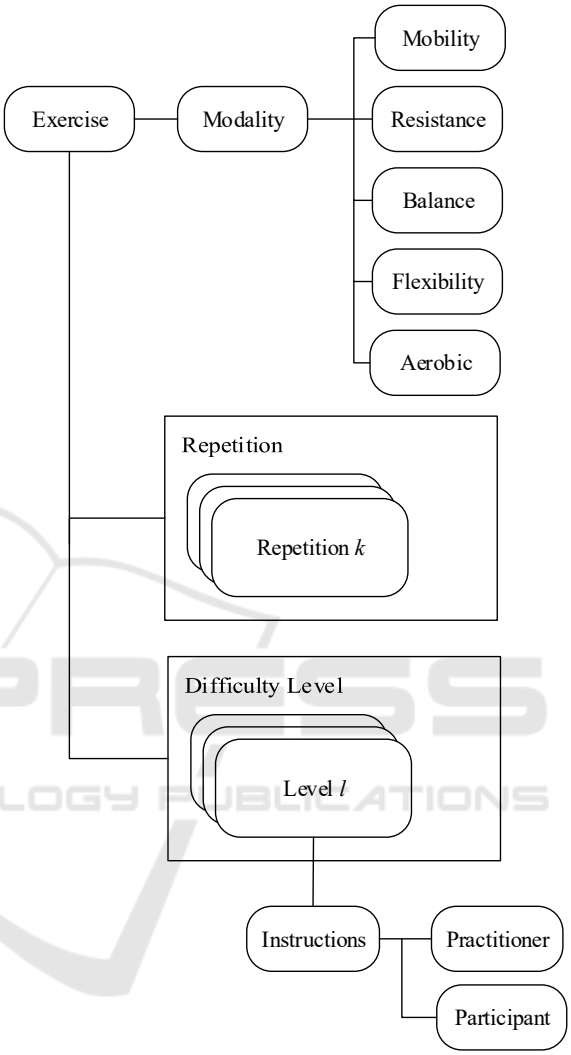

Figure 3: Information model of the physical exercise.

Table 2 presents an example of the instructions for the practitioner of a mobility exercise (i.e., ankle mobility) with four difficulty levels.

On the other hand, the instructions for the participant must include the material that is required to carry out the exercise (e.g., additional weight), a set of safety instructions (e.g., 'place the chair against a wall so that it doesn't move' or 'support both feet on the floor shoulder-width apart, torso straight and look straight ahead') and specific instructions for carrying out the exercise.

Table 1: Examples of parameters that might be used to distinguish the difficulty levels of walking, hip abductors strengthening, and calf raises exercises.

Difficulty Level	Parameters
Walking	
Walking slowly (flat surface)	Speed.
Walking at a speed of 5km/h (flat surface)	
Walking at a moderate pace carrying a light weight of no more than 4.5 kg (flat surface).	Surface inclination and additional weight.
Walking at a moderate pace carrying a light weight between 4.5 and 19 kg (inclined surface).	
Hip abductors strengthening	
Isotonic contraction, body weight, with support and without coordination element.	Resistance (body weight)
Isotonic contraction, external resistance, with support and without coordination element.	
Isotonic contraction, external resistance, without support and without coordination element.	Coordination element.
Isotonic contraction, external resistance, without support and without coordination element.	
Calf raises	
Feet hip-width apart, hands support and without coordination element.	Feet position.
Feet together, hands support and without coordination element.	

Table 2: Instructions for the practitioner of the ankle mobility exercise.

Difficulty Level	Instruction
1	Ankle plantar /dorsal flexion: sitting position.
2	Ankle circumduction: sitting position.
3	Ankle circumduction: standing position. Supported hands. hip and knee flexion from 45° to 90°.
4	Simultaneous hip, knee and ankle flexion: standing position. Supported hands. Simultaneous hip, knee, and ankle flexion, followed by maximum extension of the knee and tibiotarsal to the ground.

Concerning the specific instructions, these include guidance regarding:

- Information about the initial position, namely the alignment of the upper or lower limbs. In the case of exercises performed in a standing position with single leg support, specify whether it should be done with or without hand support.
- Movement guidelines (e.g., breath control to facilitate the performance of certain exercises).
- In situations where the participant must always return to the initial position before performing the next repetition, this information must come before the information about the number of repetitions to be performed.

Table 3 presents the specific instructions for the participant of the aforementioned ankle mobility exercise.

Finally, it should be noted that the textual instructions of Tables 2 and 3 are complemented with figures and videos. The videos will be presented and repeated while the participant is performing the exercises.

3.3.2 Practitioner Console

The practitioner console allows the definition of personalised prescriptions including the choice of the intended modality, the exercises within each modality, the level of difficulty of each one of them, the number of repetitions to be performed for each exercise, as well as the respective duration. This structure provides the module responsible for the participant interaction all the information that is required to present the sequence of exercises and respective repetitions according to the prescription characteristics (i.e., frequency, intensity, time, type, volume, and progression).

3.3.3 Participant Interaction

The participant interaction is divided into three main components:

- Session preparation – the application determines if there is a prescription containing at least one open session. If this is not the case, the participant is informed that there are no exercises available. Otherwise, the application displays an introductory screen with information about the next exercise to be performed.
- Session realization – the web-based application supports the participant during the realization of the physical exercise. While there is a session with exercises to be performed and the participant wishes to continue, the application will repeat the following actions: (i) determines the next exercise and presents the respective instruction; (ii) after the indication that the participant wants to start, repeats the video with the exercise instructions the prespecified number of repetitions; (iii) waits for the indication that the participant has finished the

exercise; and (iv) if there is an indication for a period of rest after the completion of the exercise, transmits this indication to the participant.

- Session closure – the session ends when there are no more exercises to be performed or the participant does not wish to continue. When this happens, the application gathers the participant feedback (e.g., the Borg Rating of Perceived Exertion Scale).

Table 3: Specific instructions for the participant to carry out the ankle mobility exercise.

Difficulty Level	Instruction
1	Sitting: straighten your right knee. In this position, move your toes up and down as far as you can. After completing the set number of repetitions, return to the starting position and repeat the movement to the left side.
2	Sitting: straighten your right knee. In this position, make circles with the tip of your foot (as big as you can). After completing the set number of repetitions, return to the starting position and repeat the movement to the left side.
3	Standing: support yourself on a stable surface (e.g., a wall). Raise the leg with the knee straight to about 45 degrees. In this position, make circles with the tip of your foot (as big as you can). After completing the set number of repetitions, return to the starting position and repeat the movement to the left side.
4	Standing: support yourself on a stable surface (e.g., a wall). Raise the leg with the knee straight to about 45 degrees. In this position, make circles with the tip of your foot (as big as you can). After completing the set number of repetitions, return to the starting position and repeat the movement to the left side. Standing: Support yourself on a stable surface (e.g., a wall). Raise your right knee. In this position, pull the ball of the foot up as far as you can. Then lower the leg by straightening the knee and bringing the toe down as far as you can. After completing the set number of repetitions, return to the starting position and repeat the movement to the left side.

3.3.4 Preliminary Exercise Program

To assess the feasibility of the web-based program for personalized physical exercise for community dwelling older adults a set of 35 exercises was prepared, each one with six difficulty levels. This set includes mobility, resistance, balance, flexibility, and aerobic exercises:

- Mobility exercises – head and neck mobility (sitting and standing), shoulder and arm mobility (sitting and standing), trunk and spine mobility, hip and knee mobility, or ankle mobility.
- Resistance exercises – hip abduction, hip extension, sit-to-stand, squat, hip flexion, knee extension, knee flexion, elbow flexion, lifting a weight (sitting and standing), arm spread (sitting and standing), squeezing a ball (sitting and standing), pulling towel (sitting and standing).
- Balance exercises – Straight-line walking, heel raises, or heel-walking are examples of static balance exercises, while maintaining balance in single-leg or two-leg positions are examples of dynamic exercises.
- Flexibility exercises – trunk and arm stretch, pectoral stretch, quad stretch, hamstring stretch, calf stretch, or wrist stretch.
- Aerobic exercises – dance and aerobic step.

All the exercises considered have been applied in different exercise programs for older adults, namely face-to-face exercise programs performed in clinical settings. However, since these exercises are intended to be carried out remotely, a critical aspect to consider is the suitability of the instructions provided. Therefore, to assess the adequacy of the instructions prepared for the different exercises of a preliminary exercise program, a focus group was recently approved by an ethics committee, involving potential practitioners and participants to consolidate the instructions provided by the web-based application.

4 DISCUSSION AND CONCLUSION

There are many international guidelines on exercise prescription for older adults (American College of Sports Medicine, 2009; Ferguson, 2014; US Department of Health and Human Services, 2018; World Health Organization, 2020), which agree on several recommendations, including the delivery modes and the need to include different exercise modalities and to establish a rate of progression. However, they differ in terms of frequency, duration, intensity, and the parameters to configure the progression rates. This means that the prescription of a physical exercise program must be flexible.

The information models for both the program (Figure 2) and the physical exercise (Figure 3) were defined to integrate the inherent complexity of a physical exercise program and to guarantee the flexibility of the prescriptions by allowing their personalization.

An aspect that deserved special attention was the progression of the exercise program. The rate of progression might be established by manipulating diverse factors such as exercise duration, frequency, and intensity, and by adding different elements related to motor and cognitive function or integrating multiple health- and skill-related components of physical fitness simultaneously in the same exercise.

The literature is not clear about which progression parameters should be used for each exercise modality, but some parameters might be considered to assist the prescription according to the plausibility of each modality. For general mobility exercises, an example of how the progression factors can be used is performing the exercises in single or multiple anatomical planes of movement, as well as choosing to perform exercises involving one or more joints (single-joint versus poly-joint movement) (Kisner & Colby, 2009). Regarding resistance training, some progression factors that can be explored are different types of muscle contraction within the same exercise (isotonic versus isometric versus isotonic/isometric combination), using body weight or an external resistance as a load, unstable surfaces, and the velocity at which the movement is performed, and the inclusion of a coordination element (Fragala et al., 2019). Progression factors can also be included in balance exercises, integrating the different systems involved in the control of body balance, namely the width of the base of support, external support, support surface stability, sensory input, dynamic movements that perturb the centre of gravity, coordinating element, among others (Akerman, Gonçalves & Perracini, 2011). In terms of flexibility exercises, different body positions to stretch the same muscle group can be used. When it comes to aerobic training, there are a wide variety of progression factors that can be used, depending on the type of cardiovascular training chosen (Ferguson, 2014).

In the present study, the diversity of progression factors was abstracted by difficulty levels, which resulted from the instantiation of diverse parameters such as speed, load, type of contraction, type of resistance, type of support or coordination.

In terms of the instructions for a specific exercise, each difficulty level must present instructions for the practitioner and participant. The practitioner instructions include, for instance, information related to joint name, the starting position, the inclusion of progression parameters and a description of the movements with reference to the joints involved. In turn, the instructions for the participant include the identification of the material necessary to carry out the exercise, safety instructions and specific instructions related to the initial position, movement guidelines, suggestion of specific positions or alternative movements.

Finally, concerning the practitioner and participant interaction, two different user interfaces were defined (i.e., the prescription console for the practitioner, and the participant interface).

From the implementation standpoint, the proposed models (i.e., physical exercise program and physical exercise information models, difficulty levels, instructions, and practitioner and participant interactions) were adequate and led to a coherent development of the web-based application with a preliminary set of 30 different exercises. These exercises can be aggregated to constitute coherent individual sessions, which in turn form a physical exercise program adaptable to individual needs and characteristics.

In what concerns the experience of the application of the MCR framework to develop the web-based physical exercise program and respective components and models, it is possible to conclude that the first phase of this framework (i.e., the development phase) provided efficient guidance on the methodological and practical decision-making.

To complete the development phase of the MCR framework, two additional studies are underway: (i) content validation of the practitioner and participant instructions, by conducting a focus group; and (ii) a usability study to assess the practitioner and participant user interaction, by conducting a heuristic evaluation involving experts, and a user-centred evaluation involving practitioners and potential participants.

Future work also includes the remaining three phases of the MCR framework, that is, feasibility and piloting (i.e., assessment of acceptability, compliance, and retention), evaluation (i.e., assessment of the effectiveness and cost-effectiveness, and understanding the changes introduced by the new processes), and implementation (i.e., dissemination, surveillance and long-term follow up).

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