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SUSTAINABLE PHYSICAL ACTIVITY PROGRAMS FOR YOUNG ELDERLY – A FUZZY ANALYTIC HIERARCHY PROCESS APPROACH

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Abstract Physical activity (PA) programs are useful to help young elderly stay in good shape for their senior years. These programs should be sustainable, as this would keep the users active for months and years. A PA program should build on activities that users find meaningful and/or best suited for their history of sports and exercise as well as their present physical capacity. The challenge is to make the best selection from a (long) list of possible activities. We worked out a method to help young elderly to build a sustainable PA program from a set of activities that experts have identified as contributing to health and fitness among young elderly. The method builds on the Analytical Hierarchy Process (AHP), an intuitive and much used approach.

Keywords: analytic hierarchy process, fuzzy numbers, fuzzy AHP, sustainable physical activity programs, young elderly.

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1 Introduction

Physical activity (PA) programs (understood as weekly sets of exercises) are a much-promoted modern trend – "help you reach your goals faster" (polar.com) or "motivates you to reach your health and fitness goals" (fitbit.com) – and they appear in advertising for smart watches, activity bracelets, smart phone apps, and similar, but actual use seems to lag behind the visions. The ATH 2010-2017 study in Finland (Finnish Institute for Health and Welfare (THL), 2019) shows that in the age group 30-54 years, only 30% spent several hours per week in PA programs; in the 55-74 age group, the rate goes down to 15%, and in the 75+ age group, it is only 7%. Wallén et al. (2014) studied physical exercise among 2,500 elderly Swedes (the age group 65-84). In the sample, 12% of the female and 14% of the male showed no PA; 69% of the female and 64% of the male reported regular PA only at low or medium intensity (e.g., walking a dog), which does not give sufficient health effects. The remaining 20% showed regular PA at moderate or high intensity. Moreover, the young elderly themselves found (Wallén et al. 2014) that at 60, their bodies start to impose functional limitations on them. Sports and health care professionals recommend (THL, 2019) a minimum of 150 minutes of moderate intensity PA per week for health effects. Physical activities distributed over three sessions/week allow for recovery and give better effects than a single PA session. Higher intensity and/or longer duration give more effect than lower intensity and/or shorter duration, which should be easy to understand, adopt, and follow. Nevertheless, PA among the elderly age group appears to be far too low.

Our target group is the young elderly (60-75 age group). The young elderly group is included in the ATH 2010-2017 study, and the statistics show that only 15% spend several hours/week in PA programs. When asked, 77% of people in the 55-75 age group would like to be physically more active (THL, 2019), but there is likely to be no pay-off in over-doing it if there is limited PA history, i.e., people who have not done much exercise. A PA program should build on activities that users find meaningful and/or best suited for them and their present physical capacity. The programs should be sustainable, as this would increase the chances that the users stay active for months and years.

Physical wellness comes from physical exercise to build stamina, muscle strength, and balance, and to ward off age-related serious illness; sustained physical exercise helps to meet everyday requirements of life. We have found out, in our field work, that typical forms of exercise among young elderly include walking, running, Nordic walking, gym training, group training, cross country skiing, boule, dancing, and water sports. Studies (Bangsbo et al. 2019, Jonasson, 2017, Wallén et al. 2014) show that systematic PA contributes to good quality of life in senior years.

The understanding of why physical exercise matters comes from the young elderly themselves (Carlsson et al. 2018): "it is nicer to get old if you are in good shape" or a more sober version: "to get good remaining years". These insights also capture the motivation to get in better physical shape. Given the motivation, the focus then turns to what PA and exercises to select and how to get health effects from them. The 2011 Compendium of Physical Activity (CPA) (Ainsworth et al. 2011) offers a standard for designing weekly programs. The CPA quantifies the energy cost of 821 specific physical activities in terms of the metabolic equivalent (MET). MET is "the ratio of the rate at which a person expends energy, relative to the mass of that person, while performing some specific physical activity compared to the reference, which is set by convention at 3.5 ml of oxygen per kilogram per minute (the energy expended when sitting quietly)" (Ainsworth et al. 2011).

There are other studies on PA (e.g., Hukkanen et al. 2018) that build on the use of multi-sensor systems. Then again, there is a debate about what measurements are accurate enough to show the actual intensity and effects of different physical activities (Bangsbo et al. 2019). There appears to be more focus on getting precise measurements of PA (Hukkanen et al. 2018) than on the more important goal of finding ways to get (in our case) young elderly to decide on, adopt, and use PA programs, adapt them to their own needs and goals, and then to continue using them for months and years. Thus, we do not go into details with the precision of measurements but draw from the MET (CPA) and work out PA programs with METs. METs show the energy cost (effort) of a PA relative to sitting idle (Ainsworth et al. 2011). METs are objective measures and allow for goal setting (e.g., MET-minutes per week) and systematic registration and follow-up of activities.

We run a research program for large groups of young elderly with the goal to design PA programs, find ways to implement them with digital services, and get the digital service technology accepted, as well as studying how digital services will contribute to the forming of systematic PA routines among young elderly. The young elderly participants – at present more than 660 – have two key questions (Carlsson et al. 2017, 2019): "(i) what exercises are good and useful for me; and (ii) how can I get health effects from these exercises". The CPA (Ainsworth et al. 2011), which builds on numerous studies, offers partial answers to (ii) combined with the recommendation of "a minimum of 150 minutes per week of moderate intensity PA (programs)". To help young elderly users to get answers to (i), we work out a method to support the building of sustainable PA programs. The first version that we report here uses the Analytic Hierarchy Process (AHP) to select a PA program from a set of 35 activities that are popular among young elderly.

The underlying research problem has a wider scope. We want to find out if it makes sense to tackle the composition of sustainable PA programs as a multiple criteria decision problem, for which there are much validated theory frameworks (Zeleny, 1982). Then, we will test an actual decision process with multiple criteria using AHP and find out if the choice makes sense in our research program.

The paper is structured as follows. After this introduction section, in section 2, we will work out the composition of PA programs; in section 3, we will introduce AHP and fuzzy AHP methods; in section 4, we will use the fuzzy AHP to find suitable and sustainable weekly PA programs; section 5 is a summary that offers some solutions to the research problem.

2 Physical Activity Programs

We have realized that a good way to make a PA program sustainable – to make sure that the participants will continue with the program for months (or even years) – would be to build on selections of activities (cf. Figure 1) that fit a young elderly participant, his/her PA history, and physical fitness. The CPA (Ainsworth et al. 2011) offers a basis for designing PA programs. The intensity of a PA follows three classes – light, brisk/moderate, or vigorous. The energy spent (in MET-minutes) in a PA program helps to define weekly PA goals. However, METs come from controlled experiments with adults 18-65 years old and are only partially relevant for young elderly (Ainsworth et al. 2011). There will be imprecision and variation as the young elderly are in different physical shape. For instance, 150 minutes of brisk walking (MET 3.5) gives 525 MET-minutes per week. An active young elderly with a moderate PA history and of reasonable physical fitness should easily reach a weekly level of about 600 MET-minutes (subjective personal experience), that will give short- and long-term health effects. But PA programs need to be individual and will develop over time as young elderly get in better shape.

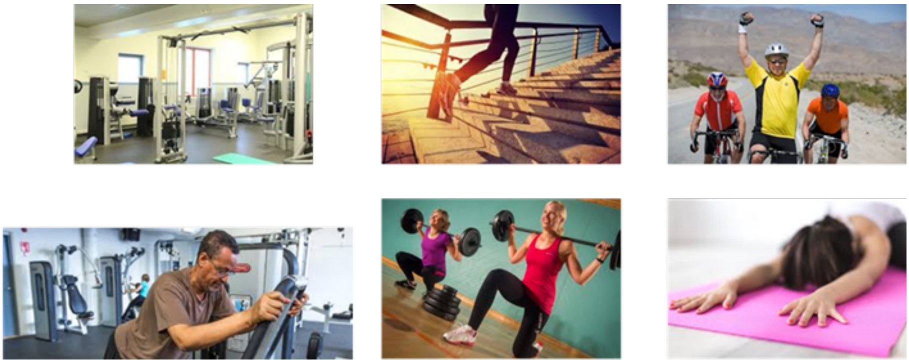

Figure 1: A selection of PA forms.

In our on-going research program, we initially used a list of 35 physical activities including their MET levels (16 of these are presented in Table 1); the CPA lists some standards (Ainsworth et al. 2011) – a brisk walk is at 5 km/h (or 10 000 steps, 3.5 MET) and 210 MET-minutes for one hour. The numbers are average standards and not precise individual measures; nevertheless, they help in finding the activity levels needed to get health effects and guide users to set their level.

Table 1: A selection (16 out of 35) of physical activities, including MET values.

Activity	CPA METs		
	Low	Moderate	High
Basketball	4,5	6,0	8,0
Soccer	4,9	7,0	10,0
Swimming	3,5	6,0	9,8
Aquajogging	2,5	4,5	6,8
Cross-country skiing	6,8	9,0	12,5
Jogging	6,0	7,0	8,0
Walking	2,8	3,5	4,3
Running	6,0	8,0	9,8
Nordic walking	3,4	4,8	6,8
Golf	3,5	4,8	5,3
Gym training	3,5	5,0	6,0
Orienteering	6,8	9,0	11,0
Cycling	6,8	8,0	10,0
Cycling indoors	4,8	7,0	8,8
Yard work	3,0	4,0	6,0
Other activity	4,1	5,6	7,5

Digital services (in the form of smartphone apps with links for storing PA data on a secure cloud service) are useful for introducing PA programs (Carlsson et al. 2017). It should be easy for the user to record activities, to find the MET-minutes and to find out the levels reached in relation to weekly goals. It is also helpful to get summaries that show PA improvements over weeks and months.

We carried out a survey among the first participants in the research program to find out the most popular forms of PA among them (165 participants; all could report several PA forms). The top seven were:

1. Walking (141/165)
2. Incidental exercise (123/165)
3. Yard work (122/165)
4. Cycling (105/165)
5. Nordic walking (85/165)
6. Cross country skiing (69/165)
7. Gym training (63/165)

The results are in line with common wisdom on what PA forms are popular among active young elderly (Bangsbo et al. 2019); there was also a long list of more exotic PA forms brought by some participants. So far it appears that the list of PA forms that we offer meets the demand fairly well.

The first version of the application we developed runs on smartphones and supports the logging and reporting of daily and weekly PA (cf. Figure 2).

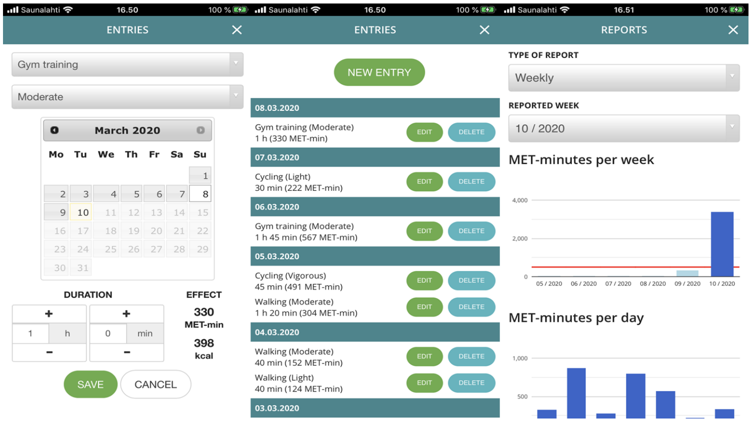

Figure 2: Posting and reporting of physical activities.

The data is stored into a database on a secure cloud server. The application collects user data in accordance with GDPR requirements, the users give their consent and appear only by pseudonym in the database. The first reactions to the program and to the digital support are positive, and we have observed that the young elderly have found the app supportive and effective.

3 Analytical Hierarchy Process and Fuzzy AHP Methods

A series of decision criteria guide the building of weekly PA programs and decide the selection of PA forms, intensity, and duration. The same type of criteria support evaluation of digital services (Yuan et al. 2015), and we will test how well they support the choice of weekly PA programs. We will use six, general form criteria (Yuan et al. 2015; actually, 5 of the 6 are UTAUT2 criteria (Venkatesh et al. 2016) that also potentially could be further specified for empirical studies:

- *Effort expectancy* – the physical effort invested in carrying out the weekly PA programs; the PA modules included have individually different effort expectancy

– *Performance expectancy* – the expected physical benefits (strength, endurance, speed, balance) the users expect from the weekly PA programs; PA modules have individually different performance expectancy
– *Social influence* – the degree to which individuals perceive support from friends, peers or PA groups for their weekly PA programs
– *Hedonic expectancy* – the expected degree of fun and pleasure derived from weekly PA programs
– *Psychological expectancy* – the expected effects of weekly PA programs in terms of sleep, stress and well-being
– *Added value* – expected payoff value relative to the time invested in weekly PA programs

Building weekly PA programs with guidance from six criteria is a multiple criteria decision problem (Zeleny, 1982). A special challenge is the fact that five of the six criteria are perceptions, not measurable facts; for added value there are good numerical methods available (Carlsson et al. 2015). A more detailed discussion of the perceptions shows that they are partly interdependent and partly conflicting (Carlsson & Fuller, 1997; 2000); effort and performance expectancy support each other (*added* effort gives *added* performance; *added* performance requires *added* effort; *added* effort gives *added* hedonic expectancy but *less* hedonic expectancy may give *added* performance). Perceptions rely on intuition and experience more than algorithms.

The AHP (Saaty & Vargas, 2002, Saaty, 2006) handles the comparison, evaluation and ranking of subjective multiple criteria by combining perceptions with systematic analysis. The AHP builds on pairwise comparison, first of the criteria, and then of the alternatives in relation to each one of the criteria; the comparisons are registered in a matrix and with matrix algebra (working out the eigenvalue) the ranking of alternatives relative to the criteria will be found (Saaty & Vargas, 2002). The classical AHP uses a precise numerical scale in the interval [1,9] to register preferences. This precision is intuitively problematic for pairwise comparison of perceptions (Vaidya & Kumar, 2006). If performance expectancy is 3 x more important to me than effort expectancy (when selecting a PA form), could it also be 2 x more important or 4 x more important? Is it at all possible to be precise on perceptions?

There is a better way to work with imprecision – the theory of fuzzy sets. There are two forms of fuzzy sets, type-1 and type-2 fuzzy sets. In type-1 fuzzy sets (Carlsson & Fuller, 2001), each element has a degree of membership in a set which is described with a membership function valued in the interval [0,1]; here 0 denotes "no membership" and 1 "full membership" – 0.8 denotes "more membership than no membership". A type-2 fuzzy set (Carlsson et al. 2015) is an extension of the type-1 fuzzy set as the membership grades themselves are type-1 fuzzy sets. They have proved useful for capturing linguistic uncertainties, e.g., words can mean different things to different people (Carlsson et al. 2015) (cf. expectancy on effort, performance, social influence, hedonic and psychological outcome; added value can be measured numerically). The membership functions of type-1 fuzzy sets are two-dimensional; the membership functions of type-2 fuzzy sets are three-dimensional and offer better tools to model uncertainties (Belohvalek et al. 2017).

Fuzzy AHP uses a linguistic scale, an interval type-2 fuzzy set, which offers more detail and flexibility than the classic AHP 9-point scale. Human judgment is normally not precise, and a 9-point scale forces cognitive compromises. The linguistic scale allows an evaluation and judgment of alternatives and criteria that allows for genuine imprecision. In real-world cases with multiple criteria (Carlsson & Fuller, 2000), decision makers simply do not know how alternatives contribute to criteria and have to offer their best guesses; if they are requested to select precise numbers from a 9-point scale offers their guesses are represented as precise estimates.

Fuzzy logic (Belohlavek et al. 2017) that builds on type-2 fuzzy sets offers a systematic, mathematically strong method to capture uncertainties in human cognitive processes. The Buckley fuzzy AHP method (Kubler et al. 2016) is one of the early contributions; it builds on the following steps (the mathematics is omitted, cf. Kubler et al. 2016; van Laarhoven & Pedrycz, 1983 for details):
The problem is formulated as a unidirectional hierarchy of criteria, (possible) sub-criteria and alternatives.

- A user compares decision elements (criteria, alternatives) pairwise in terms of importance for their upper-level criteria; the relative importance values are determined with fuzzy numbers (i.e., intervals), the numbers form fuzzy comparison matrixes on each level of the hierarchy.

- Fuzzy pairwise comparison matrices among all the criteria in the dimensions of the hierarchy system are constructed.
- The consistency of each fuzzy pairwise comparison matrix is checked; this requires that pairwise comparison values are "defuzzified" (i.e., intervals reduced to single numbers) using a graded mean integration method; this reduces much of the imprecision/uncertainty, but at this stage the comparisons have been made.
- To weigh criteria and alternatives we compute fuzzy geometric means for each row of matrices.
- Then we aggregate the fuzzy weights and fuzzy performance scores.
- The final step uses the classical AHP method to determine the best alternative.

4 Fuzzy Analytic Hierarchy Process

The experiment shown here is a young elderly individual who tries to build a weekly PA program that would be logically consistent with his idea of an effective (*effort*, *performance*) and enjoyable (*hedonic*, *social*, *psychological*) PA program. Experiments with groups of young elderly are next on the agenda (Saaty & Vargas, 2002, Vaidya & Kumar, 2006), added with features of individuals having different perceptions and preferences.

The AHP hierarchy in Figure 3 works out the most suitable weekly PA program for a young elderly participant. The goal to find the "most suitable weekly PA program (min 500 MET-minutes)" for young elderly builds on six criteria (cf. section 3). The *effort expectancy* is worked out for six forms of physical activities (Figure 3, first column); the six forms are then shown as {Physical activities} at the end of the other five criteria. The *performance expectancy* criterion is further worked out in terms of contributions to (ii.1) strength, (ii.2) endurance, (ii.3) balance and (ii.4) speed. The *social influence* comes from (iii.1) friends, (iii.2) peers, and (iii.3) PA groups (participating in the same physical activities). The *hedonic* and *psychological expectancy* are not further specified, and all six PA forms are evaluated on their contributions to fun + pleasure and less stress + better sleep + increased well-being, respectively (specified impact could be judged with better data). The *added value* is an estimate of the time used to reach the weekly goal (PA forms with higher MET values will require less time to reach weekly goals).

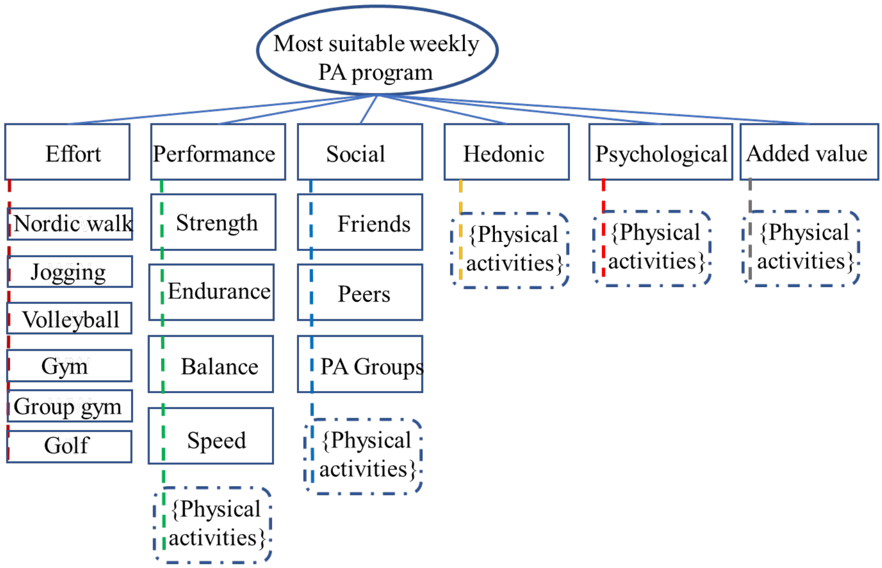

Figure 3: AHP hierarchy for deciding the most suitable PA program.

Studies have shown (Carlsson & Fuller, 1997; 2000) that multiple criteria evaluation offers cognitive challenges as soon as the number of criteria is more than 2-3 and the number of alternatives exceed 3-5 (Zeleny, 1982); here we have six criteria, two of which have 3-4 sub-criteria and six alternatives to be evaluated on the criteria and sub-criteria. Our goal is to find a weekly PA program of at least 500 MET-minutes that fits the preference structure we have decided among the criteria. The selection of physical activities include: (i) Nordic walking at moderate intensity (4.8 MET); (ii) jogging at moderate intensity (7.0 MET); (iii) volleyball in a group at vigorous intensity (6.0 MET); (iv) individual gym program at moderate intensity, 5.0 MET); (v) group gym program at moderate intensity (5.0 MET), and (vi) golf, 18 holes, walking and carrying bag (4.8 MET).

In the fuzzy AHP, the pairwise comparison and evaluation builds on a 5-point scale with intervals. Intervals are intuitively easier to deal with as four of the six criteria build on "expectancy". We have used the scale presented in Table 2 for "importance" and "preference" (e.g., *weakly more important* or *rather strongly preferred*). This is the simplest (triangular) form of fuzzy numbers; there exist other forms that capture specific types of imprecision and uncertainty (Belohlavek et al. 2018).

Table 2: Preferences as fuzzy numbers.

Code	Label	Lower	Mean	Upper
1	Equal	1	1	1
2	Weak	0.5	1	1.5
3	Rather Strong	1.5	2	2.5
4	Very strong	2.5	3	3.5
5	Absolute	3.5	4	4.5

Table 3: Ranking of primary criteria after a summary of pairwise comparisons.

Rank	Criterion	Weight
1	Performance	0.336
2	Added value	0.219
3	Effort	0.198
4	Social	0.125
5	Hedonic	0.122
6	Psychological	0.000

The evaluation used an online version of the fuzzy AHP method (www.online-output.com/fuzzy-ahp-software). Pairwise comparison which built on individual judgment over all criteria using the fuzzy 5-point scale gave the following results presented in Table 3: For example, we find that *performance* is perceived more important than *added value*, which in turn is perceived more important than *effort*.

Then we carried out pairwise comparison and evaluation of sub-criteria for the criteria "Performance" and "Social" using the same scale for "importance", which gave the following results (Table 4).

Table 4: Ranking of sub-criteria of Performance and Social.

Rank	Sub-criteria	Weight	Sub-criteria	Weight
1	Endurance	0.584	PA Groups	0.665
2	Strength	0.415	Friends	0.345
3	Speed	0.001	Peers	0.00
4	Balance	0.000		

Finally, pairwise comparison and evaluation of all the alternatives in relation to all the criteria (and sub-criteria where relevant), followed by a summation of eigenvalue vectors, gave the ranking of the alternatives relative to the goal ("most suitable weekly PA program of minimum 500 MET-minutes") presented in Table 5.

Table 5: Summary ranking of physical activities in relation to all criteria and sub-criteria.

Rank	Alternative	Weight
1	Nordic walking	0.312
2	Jogging	0.287
3	Volleyball	0.197
4	Gym (moderate)	0.115
5	Group gym	0.055
6	Golf	0.032

The ranking is intuitively acceptable as it is consistent with the ranking of the criteria: Alternatives 1 and 2 contribute to "Endurance" (ranked first sub-criterion on "Performance"), both give high expected value relative to the time invested and both require high physical effort in a weekly PA program. Alternative 3 contributes to "Performance", "Added value" and "Effort" but also more to "Social" than alternatives 1 and 2 as it requires a PA group (with rank 1 on "Social").

A weekly 2-hour 30 min program of Nordic walking at moderate intensity gives 720 MET-minutes. If we combine 1 hour 30 min of moderate Nordic walking with 1-hour vigorous volleyball, we get 792 MET-minutes. A combination of 1-hour moderate Nordic walking and a 1-hour moderate gym-program combined with 30 min of moderate group gym gives 738 MET-minutes. Thus, we can get a "most suitable weekly PA program" simply by selecting alternatives from the ranking. Updated lists can be run, for example, every week if we want to change preference profiles and get variations.

5 Summary and Conclusions

A meaningful composition of a PA program makes it more sustainable among young elderly users: Sustainable PA programs will more likely be part of everyday routines and continue to be routines for months and years to come. Sustained PA programs will also improve the probability for better health in senior years and contribute to better quality of life. This will also contribute to saving health care costs of ageing population as large groups of young elderly – and later seniors – stay healthier.

The research problem we wanted to tackle was to find out if it will make sense to compose sustainable PA programs with multiple criteria. As noted above, creating ready PA programs for young elderly is likely to positively contribute to their physical wellness and to improve quality of life. The study resulted in a solution for creating PA programs: yes, it makes sense to use a multiple criteria theory framework if there exist different preferences, a good selection of PA forms, different contributions of PA forms to preferences, and a stated goal to be attained. Although this solution is preliminary, we can conclude that the fuzzy AHP offers a useful theory framework for selecting PA forms.

As to the ranking, it can be concluded that the top list of activities is intuitive and similar to what we found in field work. Considering the criteria and sub-criteria, we found Nordic walking, jogging, volleyball, individual and group gym, and golf to be on the top of the ranking list. These activities can provide a suitable physical activity load for the young elderly.

The next step in future research will be to select groups of young elderly and build PA programs as group processes. This should show the variety of preferences for the criteria and whether some consensus on a best selection of PA programs can be found. Further research will aim to utilize the used fuzzy AHP method to create PA programs for other segments.

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