COMMISSION FOR ASSESSING THE SCIENTIFIC FOUNDATION OF A DOCTORAL DISSERTATION

TO THE TEACHING AND SCIENTIFIC COUNCIL OF THE FACULTY OF SPORT AND PHYSICAL EDUCATION

Subject: Report on the review and evaluation of the doctoral dissertation proposal of Ljubica Papić (student ID number: 5006/2019), a student from the doctoral academic studies program.

The Teaching ans Scientific Council of the University of Belgrade - Faculty of Sport and Physical Education, at its first session held on October 5, 2023, in accordance with Article 32 of the Regulations on Doctoral Academic Studies - *consolidated text* (02-no. 532/22-4 dated November 9, 2022) and Articles 41-43 of the Statute of the University of Belgrade - Faculty of Sport and Physical Education - *consolidated text* (02-no. 188/23-2 dated February 13, 2023), based on the proposal of the Council of Doctoral Academic Studies (02-no. 1836/23-2 dated September 28, 2023), made a decision to form the Commission for assessing the scientific foundation of the doctoral dissertation proposal of Ljubica Papić, titled: "PACING STRATEGY IN HALF-MARATHON AND MARATHON BASED ON PERFORMANCE LEVEL, SEX AND AGE (STRATEGIJA TEMPA TRČANJA POLUMARATONA I MARATONA U ZAVISNOSTI OD TAKMIČARSKE USPEŠNOSTI, POLA I STAROSTI)" (02-no. 1836/23-3 dated October 5, 2023). The Commission is composed of:

- Dr. Milan Matić, Associate Professor,

  University of Belgrade - Faculty of Sport and Physical Education, Commission President;
- Dr. Igor Ranisavljev, Associate Professor,

  University of Belgrade - Faculty of Sport and Physical Education, Member;
- Dr. Vladimir Mrdaković, Associate Professor,

  University of Belgrade - Faculty of Sport and Physical Education, Member;
- Dr. Miloš Marković, Associate Professor,

  University of Belgrade - Faculty of Sport and Physical Education, Member;
- Dr. Beat Knechtle, Full Professor,

  Institute of Primary Care, University of Zurich, Zurich, Switzerland, Member.

After reviewing the submitted materials, the Commission shall submit the following to the Teaching and Scientific Council:

REPORT:

Biography

Ljubica (Dušan) Papić, born on September 8, 1995, in Smederevo, Republic of Serbia, finished the Živomir Savković primary school in Kovačevac as the valedictorian and graduated from the Grammar School in Mladenovac with excellent grades in 2014.

She completed her undergraduate studies at the University of Belgrade - Faculty of Sport and Physical Education in the academic year 2017/18, graduating as the valedictorian. She then pursued her Master's degree at the same school in the academic year 2018/19 and enrolled in doctoral academic studies. Concurrently, she completed her Master's degree studies in the academic year 2020/21 at the University of Belgrade - Faculty of Medicine. During her Master's studies, she spent a semester as part of a professional development programme under an ERASMUS+ project at the University of Rome - Foro Italico, for professional development in the academic year 2019/20. In the academic year 2022/23, during her Doctoral studies, she also spent a semester at the Faculty of Sports Sciences of the University of Granada as part of the same professional development project.

She trained karate for 10 years at the Mladenovac Karate Club and won national and international medals. Since then, she has engaged in recreational running, and for the past four years, she has also run triathlons. She regularly participates in races of various distances.

Currently, she is employed on a temporary basis as an assistant at the Faculty of Sports and Physical Education, at the Department of Sport and Recreation Theory and Technology, where she has been involved in teaching as a non-employment collaborator (demonstrator) since the academic year 2018/19. She has worked as a coach at the BRAVEHEARTS recreational club since March 2023, and she gained significant practical experience during her six-year tenure as a coach for recreational runners at the Belgrade Running Club. In addition to group training, she has been providing individual fitness training to recreational athletes since 2017.

Doctoral Disertation Proposal

Ljubica Papić has proposed the topic "PACING STRATEGY IN HALF-MARATHON AND MARATHON BASED ON PERFORMANCE LEVEL, SEX AND AGE (STRATEGIJA TEMPA TRČANJA POLUMARATONA I MARATONA U ZAVISNOSTI OD TAKMIČARSKE USPEŠNOSTI, POLA I STAROSTI)" for her doctoral dissertation. In accordance with Article 31, Paragraph 2 of the Regulations on Doctoral Academic Studies, a public presentation of the proposed topic for the doctoral dissertation was delivered before the members of the Council of Doctoral Academic Studies on March 4, 2022. Based on the presentation, the proposed topic and the research project for the doctoral dissertation were positively evaluated.

Justification of the topic:

In the **introduction**, the author states that long-distance running has become popular worldwide in the last 50 years (Knechtle et al., 2018; Vitti et al., 2020). The number of participants in both international and Serbian races is increasing, and overall performance results are improving each year, with a significant increase in the number of older runners (Knechtle et al., 2018; Stojiljković et al., 2019, 2021; Vitti et al., 2020). Analyzing the top 10 marathon runners, it can be observed that their performance has improved in recent years (Knechtle et al., 2018). From 2007 to 2019, the majority of participants in the Belgrade Marathon finished the race in a time range of 4 to 4:30 hours (Stojiljković et al., 2021). These data indicate a growing number of recreational runners. Furthermore, the author mentions in the **introduction** that long-distance running includes races such as the 3,000m steeplechase, 5,000m, and 10,000m on the athletics track. Additionally, distances like 5km, 10km, 21.0975km (half-marathon), 42.195km (marathon), and races longer than 42.195km (ultramarathon) are considered long distances and are held on city streets and/or mountains (Ćuk & Rakić, 2019; Atletika, 2023), often with varying terrain configurations.

It is stated that running long distances has an impact on endurance and various positive physiological effects (Davies, 2018; Papić et al., 2019) and improves overall health (Virnitzer et al., 2022). Some of the positive effects of long-distance running include increasing maximum oxygen consumption (VO_2max), increasing respiratory capacity, improving running economy, reducing blood lactate concentration at submaximal intensity, increasing mitochondrial and capillary density, improving enzyme activity, and reducing body fat (Svank & Sharp, 2016).

The increase in the number of people running long distances could potentially lead to significant improvements in the health and lifespan of the human population, reducing the risk of cardiovascular and malignant diseases by up to 30% (Pedisić et al., 2020).

The author classifies the factors influencing long-distance running performance into external and internal. External factors include the course profile, course quality, external conditions (altitude, temperature and humidity, wind speed), nutrition and hydration before and during the race, warm-up, pacing strategy (PS), etc. When it comes to the internal factors, the author mentions the integration of muscular, cardiovascular, and neurological factors that function cooperatively (Joiner & Coile, 2008).

Regarding the performance in different age groups, women achieve the best marathon results in the age category of 30 to 34 years old, while men achieve the best results in the age category of 35 to 39 years (Nikolaidis et al., 2018). Running economy can affect the pacing strategy in long-distance running (Damasceno et al., 2011; Lima-Silva et al., 2010). The higher the running economy, the faster can the running pace can be maintained before lactate accumulation (Fay et al., 1989). With similar values of VO_2max, lactate threshold, and running economy, the speed at which VO_2max is achieved is likely to be decisive for race performance (Morgan et al., 1989; Santos-Concejero et al., 2015). Of the aforementioned performance factors, many studies indicate that pacing strategy is one of the key factors for success in long-distance races (Kais et al., 2019; Skorski & Abbiss, 2017; Smyth, 2018).

In the subsection **"Concept and Significance of Pacing Strategy in Long-Distance Running"** it is mentioned that some definitions indicate that pacing strategy refers to the distribution of energy reserves, power, and speed throughout the race without significant deceleration (Baron et al., 2011; Tucker & Noakes, 2009). It can be said that choosing one's current race pace is a combination of anticipation, knowledge, and previous experience (Skorski & Abbiss, 2017; St Gibson et al., 2006). The most important factor in choosing running pace is the race distance or duration (St Gibson et al., 2006). PS is significant in preventing homeostatic disturbances during the race (Koning et al., 2011; Tucker & Noakes, 2009). A good PS significantly reduces the risk of increased heart rate (Billat et al., 2020), reduces the risk of musculoskeletal injuries (Koning et al., 2011), and makes the race more enjoyable for recreational runners (Cuk, Nikolaidis, & Knechtle, 2019).

In the subsection **"Types of Pacing Strategies in Long-Distance Running"** the author mentions the most common PSs: even pace (without significant changes in speed) (Koning et

al., 2011; Pryor et al., 2020), positive pace (gradual decrease in speed), negative pace (gradual increase in speed) (Koning et al., 2011; Pryor et al., 2020), variable pace (with multiple significant speed changes) (Koning et al., 2011; Pryor et al., 2020), terrain-dependent pace (Pryor et al., 2020), reverse J-shaped pacing (Abbiss & Laursen, 2008; INEOS 1:59 Challenge, 2021; Nikolaidis & Knechtle, 2018a, 2018b), and U-shaped pacing (faster start and finish compared to the middle part of the race) (Abbiss & Laursen, 2008; Casado et al., 2021).

The chapter **"Previous Research"** presents the differences in PS among various long-distance running disciplines are presented (De Leeuw et al., 2018; Pycke & Billat, 2022; Menting et al., 2021). Road race analyses were conducted based on performance levels and/or gender and/or age in disciplines such as the marathon (Hernando et al., 2020; Kais et al., 2019; Muñoz-Pérez et al., 2020; Pycke & Billat, 2022), half-marathon (Hanley, 2014b), 10 km race (De Leeuw et al., 2018; Lima-Silva et al., 2010), ultramarathon (Chatzakis et al., 2021; Deusch et al., 2021; Knechtle et al., 2022; Suter et al., 2020), and triathlon (Knechtle et al., 2019). The PS of the world's top marathon runners has changed over the last 50 years (Díaz et al., 2018). From 1967 to 1988, athletes started faster than the target pace required to break the world record but significantly slowed down in the final kilometers (Díaz et al., 2018). However, since 1988, the PS has shifted from positive to negative, meaning that athletes now cover the initial kilometers of the marathon at a relatively slower pace compared to the period from 1967 to 1988 and accelerate from the 25th kilometer to the finish line (Díaz et al., 2018).
It is likely that the half-marathon has the highest number of participants (Knechtle et al., 2016). A greater growth trend in the number of participants is observed in women compared to men (Lepers & Cattagni, 2012; Stojiljković et al., 2019; Yang et al., 2022) and in older age groups (>40 years) compared to younger ones (Lepers & Cattagni, 2012). The number of male participants is always higher than the number of female participants in all long-distance races, but this gender ratio is smaller in shorter races and increases with the length of the race (Nikolaidis et al., 2021).

In the subchapter **"Running Pacing Strategy based on Performance Level"** the PS in the disciplines of 5 km, 10 km, half-marathon, and marathon are analyzed based on previous research. A search of various databases found limited studies that investigated PS in the half-marathon based on performance levels (De Leeuw et al., 2018; Hanley, 2014b). Slightly negative and positive PSs were observed in high-performance runners (De Leeuw et al., 2018) and a parabolic reverse J-shaped ST among elite runners (Hanley, 2014b). Most runners

finished the first 5 km segment relatively quickly, progressively slowing down towards the 20 km point, and then significantly accelerating during the final 1.1 km segment (Hanley, 2014b). Less pace deceleration was observed among runners who ran in a group during the race (Hanley, 2014b). Running in a group can result in less pace deceleration after the fifth kilometer, but athletes need to be careful not to join a group with a pace that is too fast (Hanley, 2014b).

The author mentions several studies that examined PS based on performance levels in marathons across different races (Kais et al., 2019; Muñoz-Pérez et al., 2020; Pycke & Billat, 2022; Santos-Lozano et al., 2014; Stojiljković et al., 2020). Positive ST is characteristic of the marathon, but faster athletes show the least loss of speed during the run (De Leeuw et al., 2018). Slower runners start significantly faster than their average pace during the first 20-25 km, after which their running speed decreases significantly below the average pace of the entire race (Santos-Lozano et al., 2014; Stojiljković et al., 2020). In the study by Stojiljković et al. (2020), on a total sample of 937 runners who completed the Belgrade Marathon in 2019, a significant difference in PS was observed in four groups formed based on performance levels. It can be observed that elite marathoners maintain an even running pace (Muñoz-Pérez et al., 2020). The medalists in world championships and Olympic Games generally run the marathon at an even pace from the 10th kilometer onwards (Hanley, 2016). It has been found that running with a group of runners with similar performance levels is more efficient than running alone in both the half-marathon and the marathon (Hanley, 2014b, 2016).

The subchapter **"Runing Pacing Strategy based on Sex"** presents the results of studies on 10 km, half-marathon, and marathon races in relation to gender are presented. The author notes that there was only one study found that compared the PS in the half-marathon between elite women and men (Stanković et al., 2019). In the Vienna half-marathon, a significant slowing down of the running pace was observed after the first 5 kilometers in the top 50 men, while the top 50 women showed better and more even running PS. Nevertheless, a slowing down of the running pace was observed in both sexes. A significant difference in running PS between sexes was found only between the 10 km and 15 km points (where women ran relatively faster than men), followed by a sharp decrease in running pace from the 15th kilometer until the end of the race. A slowing down of the average running pace was observed with an increase in the number of participants in marathon races (Stojiljković et al., 2021), and it was more pronounced in men, resulting in a reduction in the difference in average results between women and men (Lepers & Cattagni, 2012). Previous research has identified significant differences in

marathon running PS between men and women (Kais et al., 2019; Stojiljković et al., 2020) in non-elite runners, with the difference being more pronounced at higher external temperatures (Trubee et al., 2014), and there are also studies where no differences in running PS between men and women were found (Trubee et al., 2014). Positive running PS has been observed in both sexes regardless of performance level (Breen et al., 2018; De Leeuw et al., 2018; Kais et al., 2019), except for world record holders (Díaz et al., 2019). It has been found that women who run marathons recreationally start the race more conservatively, maintain a more even pace throughout the marathon and experience less pace deceleration in the final part of the race (De Leeuw et al., 2018). A study found that women ran up to 4.5% faster than men in the final kilometers (from the 40th kilometer to the finish line) (Hernando et al., 2020). It can be assumed that men overestimate their abilities at the beginning of the race, leading to significant pace deceleration during the race, and overconfidence can be one of the psychological factors that partially explain poorer running PS in men (Hubble & Zhao, 2016). When comparing male and female marathon runners in the same groups, pace deceleration is significantly more pronounced in men in the group with finishing times from 2 hours and 15 minutes to 2 hours and 30 minutes and in all groups with finishing times from 3 to 6 hours (Kais et al., 2019). However, negative running PS (Díaz et al., 2019), and even acceleration towards the end (Muñoz-Pérez et al., 2022), have been observed in men's world record holders in the marathon, while it is less frequently observed in women (Díaz et al., 2019).

In the subchapter **"Running Pacing Strategy based on Age"**, it is stated that there has been a noticeable increase in participants in marathons since 1980 in the master categories for men and women (>40 years) (Lepers & Cattagni, 2012). The largest number of participants is in the age category of 30-39 years old, both both in Serbia and abroad (Lepers & Cattagni, 2012; Stojiljković et al., 2019). Previous research indicates significant differences in running pace strategies between different age groups (Kais et al., 2019; March et al., 2011; Nikolaidis & Knechtle, 2017). Older runners had a more consistent pace compared to younger runners with similar performance levels (Kais et al., 2019; March et al., 2011; Nikolaidis & Knechtle, 2017), and a more pronounced difference was observed between groups with lower performance levels (Nikolaidis & Knechtle, 2017). Veterans had a 0.05% smaller difference between the first and second halves of the marathon compared to non-veterans (Kais et al., 2019). Some studies, however, indicate trivial differences in running pace strategies among different age groups (Nikolaidis & Knechtle, 2018a, 2019).

In the subchapter **"Comparison of Running Pacing Strategy between Races of Different Distances"** the importance of comparing running pace strategies between different long-distance races is highlighted due to a lack of understanding of the mechanism that causes a significant decrease in running speed during the second half of the marathon. The analyzed studies compared running pace strategies between half-marathons and marathons held within the same event (Vienna and Ljubljana 2017) (Cuk, Nikolaidis, & Knechtle, 2019). The analysis of running pace strategies was conducted based on sex (Cuk, Nikolaidis, & Knechtle, 2019) and age groups (Cuk, Nikolaidis, Marković, et al., 2019), while no study examined running pace strategies between half-marathons and marathons based on performance levels. A decrease in running speed during the race is observed in both marathons and half-marathons in both sexes and all age categories, with a characteristic finishing acceleration for marathon runners (Nikolaidis et al., 2019). A study on half-marathons records an acceleration towards the end of the race (Cuk, Nikolaidis, Marković, et al., 2019). Additionally, the pace is more even in both sexes and most age categories in half-marathons compared to marathons (Cuk, Nikolaidis, & Knechtle, 2019). Only one study analyzed the role of running pace and sex in races of different distances (10 km, half-marathon and marathon) with a sample of 120,472 participants over three years (De Leeuw et al., 2018). However, this study did not statistically compare the three disciplines based on these factors. Instead, a separate descriptive analysis of running pace was conducted for men and women for each discipline. Moreover, age groups were not compared to each other; instead, age was treated as a variable in the prediction equation for race results.

In the subchapter **"Conclusions and Limitations of Previous Research"** the following conclusions are listed:

1. In most studies on long-distance running performance, the marathon race has been analyzed with a large sample, considering three factors: performance level, sex and age (Kais et al., 2019; Muñoz-Pérez et al., 2020).
2. Only one study investigated performance pacing in the half-marathon based on performance level, but only among elite athletes and on a small sample (Hanley, 2014b).
3. Only one study analyzed performance pacing in the half-marathon based on sex, but it focused solely on elite runners (Stanković et al., 2019).
4. No study was found that examined PS in the half-marathon based on age.
5. Most studies compared PS in the half-marathon and marathon, with a relatively small sample, considering sex and/or age (Vienna and Ljubljana 2017) (Cuk, Nikolaidis, & Knechtle,

2019). However, none of these studies compared PS in the half-marathon and marathon based on performance level.

Considering the above, the limitations of previous research are as follows:

1. A small number of studies, mostly with small samples, have examined PS in the half-marathon, which is perhaps the most popular distance in running (Knechtle et al., 2016; Nikolaidis et al., 2021).
2. Comparisons between the half-marathon and marathon PS have been conducted on relatively small samples, focusing exclusively on sex and age.
3. No study to date has compared PS in the half-marathon and marathon based on performance level.

In accordance with the limitations of previous research, comparing PS based on performance level, sex and age in different distances held on the same day can provide a clearer answer to the question of which factors have the greatest impact on long-distance running PS. This can help address the limitations of previous research. The pilot study for this doctoral thesis provides unpublished data on PS based on performance level.

Chapter **Pilot Study** consists of subchapters **Introduction**, **Methods**, **Results and Discussion**, and **Conclusions**. In the **Introduction** of the Pilot Study, it is stated that it is a shorter version of a research titled "The pacing differences in performance levels of marathon and half-marathon runners" which was recently submitted for publication in a scientific journal. The data was collected in the same manner as will be done for the doctoral dissertation. Data collection was performed using a custom code in the Python software, designed to retrieve publicly available data from the official website of the Vienna City Marathon (Vienna City Marathon, 2023). The Pilot Study provided a more detailed insight into the research problem. The aim was to examine the differences in PS between marathon and half-marathon races in relation to the performance levels of the runners. It was hypothesized that faster runners in both disciplines would have a more even pace than slower runners. It was also assumed that both sexes of half-marathon runners would show a more even pace than marathon runners in all performance level groups formed. The **Methods** section states that an quasi-experimental with an ex-post facto design was used in the study. The official results and split times of a total of 208,760 participants in the Vienna City Marathon between 2006 and 2018 were used in this study. There were 75,492 participants in the marathon (men, N = 62,163; women, N = 13,329) and 133,268 participants in the half-marathon (men, N = 91,145; women, N = 42,123). Of the total sample, 153,308 were men and 55,452 were women. The races were held on the same day

each year, on officially certified running courses that were relatively flat, with an elevation difference of only 50 m. The marathon course also included the half-marathon course, which allowed for a comparison between these two disciplines. The dependent variables were calculated and consisted of the average running speed in each of the five race segments and the average running speed of all five race segments for each participant in both the half-marathon and the marathon (Cuk, Nikolaidis, & Knechtle, 2019). After that, the percentage of average change of speed for each of the five segments (CS 1-5) was calculated relative to the average running speed of all five race segments, while all percentages were presented in absolute (i.e., positive) values (Cuk, Nikolaidis, & Knechtle, 2019; Knechtle et al., 2022). Then, the absolute change of speed (ACS) of each participant was calculated as the average of the five CS. The independent variables consisted of the created groups based on race placement. A total of four groups were created (separated by sex and race). Descriptive statistics of the data were performed first, followed by a combined analysis of variance to determine the difference between the performance levels of the participants in the five race segments (for men and for women in the half-marathon and marathon separately). A two-way analysis of variance was also performed to determine the difference between performance levels and disciplines in relation to ACS (for men and for women). In the **Results and Discussion** section, descriptive statistics of all performance groups are presented for men and women participants. Positive PSs were observed in all men and women performance groups in both marathon and half-marathon. The results also revealed that men marathon runners in all performance groups ran faster than men half-marathon runners in the first three segments, while women marathon runners of all performance levels were faster than women half-marathon runners in all race segments. Both men and women were faster in the marathon compared to the half-marathon. This can be explained by the fact that an increase in the number of runners can worsen the results (Vitti et al., 2020). It was noticeable that the ratio of participants in the half-marathon to marathon was approximately 3:1 with women, while with men it was close to 2:1. The most significant decrease in speed was observed in the fourth segment, and it was more pronounced in slower groups, which can be attributed to the accumulated fatigue due to inadequate PS and the long distance covered by the fourth segment (Cuk, Nikolaidis, & Knechtle, 2019; Hanley, 2014b). The results of the pilot study demonstrate a significant influence of performance levels on the variability of running pace in the five race segments in both disciplines and sexes. Similar conclusions were drawn in other studies that examined this in marathon races only (Kais et al., 2019; Nikolaidis & Knechtle, 2017). Interestingly, a more pronounced pace slowdown during the half-marathon was observed in runners who ran slower than their

predicted finishing time, while those who ran faster than the predicted time had a more even running pace (Piacentini et al., 2019). Metabolically speaking, maintaining a even pace could be the most efficient strategy for completing long-distance races (Rapoport, 2010). When compared to the results from the pilot study, it can be assumed that runners with higher performance levels achieved results better than expected due to a more even running pace. In the marathon and half-marathon runners categorized as a high-performance group, there was no significant change in running pace towards the end of the race, which can be explained by the fact that these runners had better energy distribution compared to weaker runners. Therefore, the number of years a person has been running and the number of races completed are directly related to PS, regardless of age, sex and current performance level. Experienced runners are expected to maintain a more even pace, while less experienced ones experience to show a more significant pace slowdown (Deaner et al., 2015), which aligns with the results of the pilot study. The examination of the relationship between performance levels and disciplines determined that marathon runners in all performance categories have a much more variable running pace compared to half-marathon runners. In comparison to men, these comparisons in women show significant differences in the variability of pace between women running the marathon and the half-marathon, although the differences are less pronounced ($\eta^2 = 0.032$). The author suggests that a higher relative proportion of slow-twitch muscle fibers in women may be one of the reasons for faster oxygen extraction dynamics in peripheral and pulmonary blood at moderate exercise intensities compared to men (Beltrame et al., 2017). Additionally, a more capable muscle metabolism in synthesizing adenosine triphosphate (ATP) through oxidative phosphorylation is mentioned as an explanation for the lower variability of pace in women (Ansdell et al., 2020). The author believes that the less pronounced difference in the variability of running pace between the half-marathon and marathon in women is mostely caused by their physiology. A significant influence of performance level and discipline on ACS was observed in both men and women. The hypothesis that faster runners in both marathon and half-marathon races would exhibit a more even pace (i.e., showing fewer speed changes) than slower runners was confirmed. However, the difference in ACS between women in the marathon and half-marathon had a trivial effect size, partially confirming the hypothesis that both men and women in half-marathon runners would demonstrate a more even pace compared to marathon runners in all performance groups. In conclusion, the results of this study demonstrate a significant influence of performance levels on the variability of pace in participants of both disciplines and sexes.

In the chapter **"Research Problem, Subject, Aims, and Tasks"** it is stated that the research problem is the running PS in the half-marathon and marathon races. The subject of the research is the analysis of PS in the half-marathon and marathon based on performance level, sex, and age. The research aims and tasks are defined are based on the research problem and subject.

Aim 1: Comparison of pacing strategies in half-marathon and marathon.

a) Comparison of pacing strategies in half-marathon and marathon based on performance level.

b) Comparison of pacing strategies in half-marathon and marathon based on sex.

c) Comparison of pacing strategies in half-marathon and marathon based on age.

Aim 2: Analysis of pacing strategies in half-marathon.

a) Analysis of pacing strategies in half-marathon based on performance level.

b) Analysis of pacing strategies in half-marathon based on sex.

c) Analysis of pacing strategies in half-marathon based on age.

Aim 3: Analysis of pacing strategies in marathon.

a) Analysis of pacing strategies in marathon based on performance level.

b) Analysis of pacing strategies in marathon based on sex.

c) Analysis of pacing strategies in marathon based on age.

The research aims will be achieved by carrying out the following tasks:

a) Obtaining approval from the Ethics Committee.

b) Collecting publicly available data from the official website of the Vienna Marathon for 17 half-marathon and marathon races (from 2006 to 2023, except for the year 2020).

c) Database organization and cleaning.

d) Statistical analysis of the data.

e) Interpretation of the research results.

In the chapter **"Research Hypotheses"** hypotheses are defined based on a review of previous research and in line with the research aims.

Hypothesis 1: The pacing of a half-marathon is more even compared to the pacing of a marathon.

a) The pacing of half-marathoners is more even compared to the pacing of marathoners in all performance groups and for both sexes.

b) Women pace more even compared to men in both races, with greater differences in marathon than in half-marathon.

c) Middle-aged runners pace more even compared to younger and older runners, with greater differences in marathon than in half-marathon.

Hypothesis 2: The pacing strategy of a half-marathon is positive.

a) Runners of higher performance levels, both sexes, pace more even compared to runners of lower performance levels in the half-marathon.

b) Women pace more even compared to men in the half-marathon.

c) Middle-aged runners of both sexes pace more even compared to younger and older runners in the half-marathon.

Hypothesis 3: The pacing strategy of a marathon is positive.

a) Runners of higher performance levels, both sexes, pace more even compared to runners of lower performance levels in the marathon.

b) Women pace more even compared to men in the marathon.

c) Middle-aged runners of both sexes pace more even compared to younger and older runners in the marathon.

In the **Methods** chapter, under the subheading **"Research Design"** it states that the study is quasi-experimental with an ex-post facto design.

In the subheading **"Sample of Participants"** the author mentions that the participants will be all the runners who took part in the Vienna Half-Marathon and Marathon from 2006 to 2023 (except for 2020 when the races were not held due to Covid), based on official data from the Vienna Marathon organizer's website. Runners with missing data such as sex, age, results in any race segment, final result and race placement will be excluded from the analysis. Based on a preliminary data review, the sample will consist of over 210,000 participants.

The subheading **"Race Details"** explains that the Vienna Half-Marathon and Marathon are held every year on the Sunday at the end of April. During the observed period from 2006 to 2023, both race courses are officially certified and located on a fairly flat terrain with an elevation difference of only 50 meters (ranging from 154 m to 210 m). In comparison, the Berlin Marathon, known as the "fastest marathon," has an elevation difference of 21 meters.

The marathon course fully encompasses the half-marathon course and remained almost identical throughout the analyzed period of 17 years (2006-2023, except 2020). Available meteorological data during the race (temperature, air humidity, wind speed) will be obtained from the official website.

The subheading **"Data Collection and Processing"** explaines the process of data retrieval from the official Vienna Marathon website (Vienna City Marathon, 2023), including exporting

the data for each year, discipline and sex into Excel documents. The half marathon and marathon will be divided into 5 segments and will constitute the dependent variables of the research. For the marathon distance, the first 4 segments will be 10 kilometers each, and the fifth segment will be 2.195 kilometers, while for the half marathon distance, each segment will be half the size (Cuk, Nikolaidis, & Knechtle, 2019; Nikolaidis, Cuk, et al., 2019). Then, the average running speed for the entire race and for each of the five race segments will be calculated for each participant in the half-marathon and marathon (Cuk, Nikolaidis, & Knechtle, 2019; Nikolaidis, Cuk, et al., 2019). The first independent variable will be the performance level, with participants divided into four groups (quartiles) based on their performance level (separately for sex and discipline). The second independent variable will be the sex of the participants, i.e., men and women. The third independent variable will be six age categories, each spanning 10 years (except for the youngest participant category, which has a wider range: 18-29 years). The fourth independent variable will be the type of race: half-marathon and marathon.

In the subchapter **"Statistical Data Analysis"** it is stated that descriptive statistics will be followed by an examination of the normality of data distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests, as well as visual inspection of histograms and Q-Q plots. Bonferroni's test will be used for all post hoc comparisons. Effect size will be represented by eta-squared (η^2) and described using conventional guidelines: >0.01 = small effect, >0.06 = moderate effect, >0.14 = large effect (Cohen, 1988). The alpha level will be set at $p < 0.05$. All statistical analyses will be conducted using Microsoft Office Excel 2019 (Microsoft Corporation, Redmond, VA, USA) and IBM SPSS Statistics 20 (IBM, Armonk, NY, USA).
In *the Comparison of Pacing Strategies in Half-Marathon and Marathon* to confirm hypothesis 1, a combined analysis of variance (ANOVA) will be used to explore the effect of the race (half-marathon and marathon) on participant ACS in the five race segments. Subsequently, an independent t-test will be conducted to examine the difference in ACS between the half-marathon and marathon. In *the Comparison Based on Performance Level* to confirm hypothesis 1a, a two-way ANOVA of different groups will be conducted to investigate the effect of performance level and discipline (half-marathon and marathon) on ACS (separately for men and women). The same procedure will be used to examine the interaction of discipline and performance level (discipline × performance level). In *the Comparison Based on Sex* to confirm hypothesis 1b, a two-way ANOVA of different groups will be conducted to explore the influence of sex and discipline on ACS. The same procedure will be used to investigate the

interaction of discipline and sex (discipline × sex). In *the Comparison Based on Age* category to confirm hypothesis 1c, a two-way ANOVA of different groups will be conducted to examine the effect of age category and discipline on ACS (separately for men and women). The same procedure will be used to investigate the interaction of discipline and age category (discipline × age category). In *the Analysis of Pacing Strategies in Half-Marathon* to confirm hypothesis 2, a repeated measures ANOVA will be conducted to examine the difference in average speed between each of the five race segments in the overall sample of the half-marathon. In *the Analysis of Pacing Strategy Based on Performance Level,* to confirm hypothesis 2a, a combined ANOVA will be conducted to investigate the influence of performance level on change of speed in the five race segments (for men and women separately). This statistical analysis will be used to assess the interaction of segment (CS1-5) and performance level (segment × performance level), main effects for segment (within-subject factor), and main effects for performance level (between-subjects factor). For the sake of further analysis and confirmation of hypothesis 2a, a two-way ANOVA of different groups will be conducted to examine the influence of performance level and sex on ACS. The same procedure will be used to investigate the interaction of sex and performance level (sex × performance level). This way, ACS will be analyzed between men and women within each performance group in the half-marathon. In *Analysis of Pacing Strategies Based on Sex,* to confirm hypothesis 2b, a combined ANOVA will be conducted to examine the effect of sex on change of speed in the five race segments. This statistical analysis will be used to assess the interaction between segment (CS) and sex (segment × sex), main effects for segment (within-subject factor), and main effects for sex (between-subjects factor). In *the Analysis of Pacing Strategies Based on Age,* to confirm hypothesis 2c, a combined ANOVA will be conducted to examine the effect of age category on change of speed in the five race segments (separately for men and women). This statistical analysis will be used to assess the interaction of segment (CS) and age category (segment × age category), main effects for segment (within-subject factor), and main effects for age category (between-subjects factor). For a more detailed analysis and confirmation of hypothesis 2c, a two-way ANOVA of different groups will be conducted to examine the influence of age category and sex on ACS. The same procedure will be used to investigate the interaction between sex and age category (sex × age category), main effects of sex, and age category. This way, ACS will be analyzed between men and women within each age category in the half-marathon. In *Analysis of Pacing Strategies in Marathon,* to confirm hypothesis 3, a repeated measures ANOVA will be used to examine the difference in average speed between each of the five race segments in the overall sample of the marathon. In *Analysis of Pacing*

Strategies Based on Performance Level, to confirm hypothesis 3a, a combined ANOVA will be conducted to examine the effect of performance level on speed change in the five race segments (separately for males and females). This statistical analysis will be used to assess the interaction of segment (CS1-5) and performance level (segment × performance level), main effects for segment (within-subject factor), and main effects for performance level (between-subjects factor). For a more detailed analysis and confirmation of hypothesis 3a, a two-way ANOVA of different groups will be conducted to examine the influence of performance level and sex on ACS. The same procedure will be used to investigate the interaction of sex and performance level (sex × performance level). This way, ACS will be analyzed between men and women within each performance group in the marathon. In *the Analysis of Pacing Strategies Based on Sex,* to confirm hypothesis 3b, a combined ANOVA will be conducted to examine the effect of sex on change of speed in the five race segments. This statistical analysis will be used to assess the interaction of segment (CS) and sex (segment × sex), main effects for segment (within-subject factor), and main effects for sex (between-subjects factor). In *the Analysis of Pacing Strategies Based on Age,* to confirm hypothesis 3c, a combined ANOVA will be conducted to examine the effect of age category on change of speed in the five race segments (separately for men and women). This statistical analysis will be used to assess the interaction of segment (CS) and age category (segment × age category), main effects for segment (within-subject factor), and main effects for age category (between-subjects factor). For a more detailed analysis and confirmation of hypothesis 3c, a two-way ANOVA of different groups will be conducted to examine the influence of age category and sex on ACS. The same procedure will be used to investigate the interaction of sex and age category (sex × age category), main effects for sex, as well as age category. This way, ACS will be analyzed between men and women within each age category in the marathon.

In the chapter **"Potential significance of the research"** the author states that half-marathon and marathon running is a physical activity spread all over the globe, and PS is an important factor for achieving results in these disciplines. The innovations in this study compared to previous reviewed research are as follows:

1. Analysis of a large sample of participants.
2. Comparison of half-marathon and marathon distances held on the same day, on the same track, and under similar external conditions.
3. Comparison and analysis will be conducted based on three factors: performance level, sex and age.

4. Analyses of the half-marathon pacing strategy will be conducted based on three factors: performance level, sex and age.

The research results will provide valuable information to experts, coaches, athletes and recreational runners with regard to controlling fatigue during efforts exertion to achieve the best race results. This information will be specific to the race distance, performance level, sex and age of the runners. The practical significance of the research is that it makes it possible to adopt a specific approach to the overall training process, individual training sessions and races based on these categories. Considering that PS also depends on external conditions, the research findings can be significant in selecting a race to achieve the best result based on terrain configuration, weather forecast, season, etc. Furthermore, the results of this research can enable better planning of PS during races, depending on the category the runner belongs to, which will impact the achieved race result. Since pace is influenced by internal and external factors, the research findings will help runners better predict their abilities in given conditions to meet the planned PS and achieve the best outcome. By developing awareness and skills in managing fatigue during training and races, the risk of homeostatic disturbances and injuries should be reduced, allowing runners in every category to achieve better results. Considering that the majority of half-marathon and marathon participants engage in running recreationally, their education is important to ensure that running contributes to their health and quality of life. This can help avoid negative health effects resulting from poor PS and increase runners' motivation to engage in running.

The References chapter lists 196 bibliographic entries, the majority of which were published in prominent international scientific journals. Approximately 65% of the references were published in the last ten years.

Proposal of mentors, mentor consent, and their publications list

Considering the complexity of the research problem addressed by the candidate in the justification of their doctoral dissertation proposal and their collaboration during the research preparation, we propose two mentors for the realization of the doctoral dissertation project:

1. Dr. Stanimir Stojiljković, Full Professor, University of Belgrade - Faculty of Sport and Physical Education, Serbia.
2. Dr. Ivan Ćuk, Assistant Professor, University of Belgrade - Faculty of Sport and Physical Education, Serbia.

Both Full Professor Dr. Stanimir Stojiljković and Assistant Professor Dr. Ivan Ćuk, meet the requirements specified by the Standards for the Accreditation of Doctoral Study Programs and agree to be mentors for the realization of Ljubica Papić's doctoral dissertation based on the proposed topic.

We are attaching a list of publications by Full Professor Dr. Stanimir Stojiljković and Assistant Professor Dr. Ivan Ćuk in international scientific journals over the last 10 years, thematically related to the scientific field of Physical Education and Sports, the same domain that the proposed topic is part of. Furthermore, we emphasize that some of these publications are closely related to the proposed topic. The publications are as follows:

Dr. Stanimir Stojiljković, Full Professor

Popovic, D., Damjanovic, S., Popovic, B., Kocijancic, A., Labudović, D., Seman, S., **Stojiljković, S**., Tesic, M., Arena, R., & Lasica, R. (2022). Physiological behavior during stress anticipation across different chronic stress exposure adaptive models. *Stress - The International Journal on the Biology of Stress*, 25(1): 14-21. DOI: 10.1080/10253890.2021.2006178 (M22)

Strelić, S., Ranisavljev, I., Ćosić, M., & **Stojiljković, S**. (2022). Time ratio of the triathlon race segments in the olympic and sprint distances in competitors of different performance levels. *Journal of Physical Education and Sport*, 22(3): 701-708. (M24)

Kojić, F., Ranisavljev, I., Ćosić, D., Popović, D., **Stojiljković, S**., Ilić, V. (2021). Effects of resistance training on hypertrophy, strength and tensiomyography parameters of elbow flexors: role of eccentric phase duration. *Biology of Sport*, 38 (4): 587-594. (M22)

Seman, S., Srzentić Dražilov, S., Ilić, V., Tešić, M., **Stojiljković, S**., Arena, R., & Popović, D. (2021). Physical activity and exercise as an essential medical strategy for the COVID-19 pandemic and beyond. *Experimental Biology and Medicine*, 246(21): 2324-2331. https://doi.org/10.1177/15353702211028543 (M22)

Kojic, F., Đurić, S., Ranisavljev, I., **Stojiljkovic, S**., Ilic, V. (2021). Quadriceps femoris cross-sectional area and specific leg strength: relationship between different muscles and squat variations. *PeerJ*, 9:e12435 https://doi.org/10.7717/peerj.12435 (M22)

Stojiljković, S., Matić, M., Papić, Lj. (2019). The Trend in the Number of Participants from Serbia in the Belgrade Marathon from 2007 to 2019: The Effect of Gender and Age. *Facta Universitatis, Series Physical Education and Sport*, 17 (2): 353-369. (M24)

Podstawski, R., Markowski, P., Clark, C.C.T., Choszcz, D., Ihász, F., **Stojiljković, S**., Gronek, P. (2019). International Standards for the 3-Minute Burpee Test: High-Intensity Motor Performance. *Journal of Human Kinetics*, vol. 69, br. 1, str. 137-147. (M23)

Popovic, D., Damjanovic, S.S., Plecas-Solarovic, B., Pešic, V., **Stojiljkovic, S**., Banovic, M., Ristic, A., Mantegazza, V., Agostoni, P. (2016). Exercise capacity is not impaired after acute alcohol ingestion: a pilot study. *Journal of Cardiovascular Medicine*, vol. 17, br. 12, str. 896-901. (M23)

Popovic D., Popovic B. M., Plecas-Solarovic B. A., Pesic V., Markovic V., **Stojiljkovic S**., Vukcevic V. M., Petrovic I. M., Banovic M. D., Petrovic M. Z., Vujisic-Tesic B. D., Ostojic M. C., Ristic A. D., Damjanovic S. S. (2013). The interface of hypothalamic-pituitary-adrenocortical axis and circulating brain natriuretic peptide in prediction of cardiopulmonary performance during physical stress. *Peptides*, vol. 47, str. 85-93. (M22)

Popović, D**.,** Ostojić, M.C**.,** Popović, B**.,** Petrović, M**.,** Vujisić-Tešić, B**.,** Kocijančić, A**.,** Banović, M**.,** Arandjelović, A**., Stojiljković, S.,** Marković, V**.,** Damjanović, S.S. (2013). Brain natriuretic peptide predicts forced vital capacity of the lungs, oxygen pulse and peak oxygen consumption in physiological condition. *Peptides*, vol. 43, str. 32-39. (M22)

Prebeg, G., Ćuk, I., Suzović, D., **Stojiljković, S**., Mitić, D., Jarić, S. (2013). Relationships among the muscle strength properties as assessed through various tests and variables. Journal of Electromyography and Kinesiology, vol. 23, issue 2, str. 455-461. (M21)

Dr. Ivan Ćuk, Assistant Professor

Fariod, M., Olher, R. R., Sousa, C. V., Scheer, V., **Cuk, I**., Nikolaidis, P. T., Thuany, M., Weiss, K., & Knechtle, B. (2023). Pacing Variation in Multistage Ultramarathons: Internet-Based Cross-Sectional Study. JMIR Formative Research, 7. https://doi.org/10.2196/46650 (M24)

Stjepanovic, M., Knechtle, B., Weiss, K., Nikolaidis, P. T., **Cuk, I**., Thuany, M., & Sousa, C. V. (2023). Changes in pacing variation with increasing race duration in ultra-triathlon races. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-30932-1 (M21)

Knechtle, B., **Cuk, I**., Villiger, E., Forte, P., Thuany, M., Andrade, M. S., Nikolaidis, P. T., & Weiss, K. (2023). Performance and pacing of professional IRONMAN triathletes: the fastest IRONMAN World Championship ever—IRONMAN Hawaii 2022. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-42800-z (M21)

Thuany, M., Valero, D., Villiger, E., Forte, P., Weiss, K., Nikolaidis, P. T., Andrade, M. S., **Cuk, I**., Sousa, C. V., & Knechtle, B. (2023). A Machine Learning Approach to Finding the Fastest Race Course for Professional Athletes Competing in Ironman® 70.3 Races between 2004 and 2020. International Journal of Environmental Research and Public Health, 20(4), 3619–3619. https://doi.org/10.3390/ijerph20043619 (M24)

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Knechtle, B., Valero, D., Villiger, E., Thuany, M., Andrade, M. S., Nikolaidis, P. T., **Cuk, I**., & Weiss, K. (2023). Comparing the Performance Gap Between Males and Females in the Older Age Groups in IRONMAN® 70.3: An Internet-Based Cross-Sectional Study of More Than 800,000 Race Records. Sports Medicine - Open, 9(1). https://doi.org/10.1186/s40798-023-00636-x (M21a)

Thuany, M., Vieira, D., de Paula, H., Nikolaidis, P. T., Scheer, V., Weiss, K., **Cuk, I**., Knechtle, B., & Gomes, T. N. (2023). The Relative Importance of Training and Social Support for Runners' Performance: A Cross-Sectional Study. Sports Medicine - Open, 9(1). https://doi.org/10.1186/s40798-023-00557-9 (M21a)

Weiss, K., Thuany, M., Scheer, V., Ouerghi, N., Andrade, M. D. S., Nikolaidis, P. T., **Ćuk, I.**, & Knechtle, B. (2023). How to end up on the podium after running a 6-days-run with type 1 diabetes mellitus-A case study and literature review. *European Review for Medical and Pharmacological Sciences*, *27*(1), 88-97. https://doi.org/10.26355/eurrev_202301_30856 (M22)

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Markovic S., **Cuk I.,** Radonjic V., & Momcilovic V. (2021). Power characteristics in senior basketball players - competitive-level differences. Facta Universitatis, Series: Physical Education and Sport, 19(1), 69–79. https://doi.org/10.22190/FUPES210417011M (M24)

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Opinion and Proposal of the Committee

The proposal for Ljubica Papić's doctoral dissertation is written in English. The proposed topic has the following objectives: 1. Comparison of pacing strategies in half-marathon and marathon; 2. Analysis of pacing strategies in half-marathon; 3. Analysis of pacing strategies in marathon. The topic is formulated based on a careful analysis of extensive bibliographic material. The research problem is thoroughly explained, and the aim and hypotheses are clearly formulated. The proposed research methods enable the achievement of the research aims. The research is highly significant from a theoretical perspective and will have significant practical applications.

We propose that the Teaching and Scientific Council accepts the Committee's report and sends a decision to the Council for Scientific Fields of Social Sciences and Humanities, approving the proposal topic of Ljubica Papić's doctoral dissertation entitled: "PACING STRATEGY IN HALF-MARATHON AND MARATHON BASED ON PERFORMANCE LEVEL, SEX AND AGE (STRATEGIJA TEMPA TRČANJA POLUMARATONA I MARATONA U ZAVISNOSTI OD TAKMIČARSKE USPEŠNOSTI, POLA I STAROSTI)" and appointing Full Professor Dr. Stanimir Stojiljković from the University of Belgrade - Faculty of Sport and Physical Education, and Assistant Professor Dr. Ivan Ćuk from the University of Belgrade - Faculty of Sport and Physical Education, as mentors.

In Belgrade, on November 10th, 2023. Committee Members:

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Dr. Milan Matić, Associate Professor,
University of Belgrade - Faculty of Sport and Physical Education, Committee Chair.

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Dr. Igor Ranisavljev, Associate Professor,
University of Belgrade - Faculty of Sport and Physical Education, Committee Member.

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Dr. Vladimir Mrdaković, Associate Professor,
University of Belgrade - Faculty of Sport and Physical Education, Committee Member.

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Dr. Miloš Marković, Associate Professor,
University of Belgrade - Faculty of Sport and Physical Education, Committee Member.

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Dr. Beat Knechtle, Full Professor,
Institute of Primary Care, University of Zurich, Zurich, Switzerland, Committee Member.