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PHYSICAL ACTIVITY AND HEALTH IN PREGNANCY
AND THE USE OF ONLINE TOOLS

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PHYSICAL ACTIVITY AND HEALTH IN PREGNANCY AND THE USE OF ONLINE TOOLS

PHD DISSERTATION

Supervisor:

Anna Szumilewicz, assoc. prof. of GUPES

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Paper 1

Yu, H.; He, J.; Szumilewicz, A. Pregnancy activity levels and impediments in the era of COVID-19 based on the health belief model: A cross-sectional study. *Int. J. Environ. Res. Public Health* (2022) 19, 3283. https://doi.org/10.3390/ijerph19063283
MEiN points value: 140; IF: 4.614

Paper 2

Yu, H.; He, J.; Wang, X.; Yang, W.; Sun, B.; Szumilewicz, A. A comparison of functional features of Chinese and US mobile apps for pregnancy and postnatal care: A systematic app store search and content analysis. *Front. Public Health* (2022) 10, 1–12. https://doi.org/10.3389/fpubh.2022.826896
MEiN points value: 100; IF: 6.461

Paper 3

Yu, H.; He, J.; Li, K.; Qi, W.; Lin, J.; Szumilewicz, A. Quality assessment of pre- and postnatal nutrition and exercise mobile applications in the United States and China. *Front. Nutr.* (2023) 9:942331. https://doi.org/10.3389/fnut.2022.942331
MEiN points value: 70; IF: 6.590

Paper 4

Yu, H.; Santos-Rocha, R.; Radzimiński, Ł.; Jastrzębski, Z.; Bonisławska, I.; Szwarc, A.; Szumilewicz, A. Effects of 8-week online, supervised high-intensity interval training on the parameters related to the anaerobic threshold, body weight, and body composition during pregnancy: A randomized controlled trial. *Nutrients* (2022) 14, 5279. https://doi.org/10.3390/nu14245279
MEiN points value: 140; IF: 6.706

The total MEiN points value: 450; IF: 24.371

2. Introduction

Pregnancy represents a unique period in a woman's life, and women's health has garnered much attention in the context of women's rights advocacy. Although having children has numerous benefits, women can also face many challenges due to pregnancy, such as obesity, diabetes, nausea (with or without vomiting), discomfort in the pelvic girdle, and other musculoskeletal issues [1]. The National Center for Health Statistics indicated that maternal mortality has increased by 33% in the second trimester and 41% in the third trimester since the onset of the Coronavirus disease 2019 (COVID-19) pandemic [2]. These changes may be attributed to conditions directly related to COVID-19 such as respiratory infections or conditions aggravated by viruses such as hypertension, diabetes, and cardiovascular disease [2]. They can also be a result of more sedentary lifestyle typical for the pandemic lock down and the increased use of online technology to perform many professional and everyday activities in the post-lockdown reality.

Physical inactivity is prominent health risk factor throughout the pregnancy to postnatal stages. It may cause both short- and long-term health issues for women [3,4], such as the need for obstetric intervention (e.g., cesarean section and instrumental delivery) [5], a greater likelihood of fetal macrosomia (i.e., a large-for-gestational-age baby) [6], a greater risk of pregnancy related complications (e.g., gestational diabetes, hypertension, pre-eclampsia) [7], and poor cardiovascular health [8].

A minimum of 150 min per week of moderate-to-vigorous exercise during pregnancy is safe and recommended in the absence of obstetric or medical complications or contraindications by credible gynecology, obstetrics, and sports medicine institutes, including the World Health Organization [9-12]. According to current evidence-based guidelines [13,14], there are no known risks associated with moderate-intensity exercise in women with uncomplicated pregnancies. Furthermore, vigorous exercise during pregnancy among women who are well trained prior to conception has no negative effects on the process of pregnancy, labor, or the unborn child [15]. Aerobic exercise can improve aerobic fitness in pregnant women, promote fat burning, and delay elevations in blood lactate levels during graded exercise testing [16-18]. However, pregnancy is a memorable life stage that may elicit distinct variables that motivate or impede physical activity (PA) [19]. Pregnant women may want to perform PA for their own health and that of their baby, but they may struggle to do so. Recent studies have revealed that pregnant women tend to be sedentary [19]. Major reasons and factors for this include: a lack of desire to be active, which pregnant women often mention as a barrier to exercise [20]; unawareness of the value of prenatal physical activity, how much exercise is needed, and how to exercise safely [19]; social variables, such as a lack of support from friends, family, and doctors to be active, which can significantly influence prenatal physical activity levels; and traditional culture, as pregnancy has historically been viewed as a time for relaxation and recuperation [21]. Additionally, COVID-19 and its corresponding isolation periods may harm the health of pregnant women and introduce various dilemmas related to prenatal physical activity [22].

The health belief model (HBM) [23] is a classic and widely used psychological theory in health science that may be employed to determine the most critical factors across geographies, economies, and cultures and shed light on the relationship between psychological, demographic, social and lifestyle factors. The HBM defines the key factors that influence health behaviors as an individual's perceived threat to sickness or disease (perceived susceptibility), belief of adverse consequence (perceived severity), potential positive benefits of action (perceived benefits), perceived barriers to action, exposure to factors that prompt action (cues to action), health motivation, and confidence in ability to succeed (self-efficacy) [23]. Using this model to better understand the pregnant women behaviors related to physical activity seems very interesting.

During the perinatal period, everything from pregnancy and delivery to nutrient consumption [24], life taboos [25], and newborn physical examinations [26] must be closely monitored. Pregnancy and postnatal education and support provided by a multidisciplinary team of specialists (e.g., doctors, midwives, trainers, and psychotherapists) may enhance the quality of care [27,28]. However, they may be too expensive or unavailable in impoverished countries [29,30]. What is more, a lack of professional coaches, financial support, and infrastructure may hinder the provision of pregnancy to postpartum care, including targeted exercise programs from a multidisciplinary team of specialists. Therefore, it is important to look for solutions to prevent these barriers, including through the use of online tools.

The tremendous surge in popularity of mobile health (mHealth) and electronic health (eHealth) has changed the conventional model of healthcare services in recent years [31]. More people consult health and lifestyle information via mobile applications (apps), which have the potential to significantly improve current therapy and minimize reliance on professional team health services [32,33]. Furthermore, health-related apps contributed to safe social distance and lower infection rates during the COVID-19 pandemic and its associated isolation periods [34].

According to a recent survey in Switzerland, pregnancy to postpartum applications (apps) are becoming increasingly popular [35]: 91% of parents use digital media to learn about their child's health and development [36]. Evidence from systematic reviews and randomized controlled trials (RCTs) suggests that pregnancy and postpartum apps are generally effective in promoting maternal and newborn physical health (e.g., weight management, postpartum recovery, and infant care) [7,37,38]. In addition, their cost-effectiveness and convenience were beneficial during the COVID-19 pandemic [39]. Nevertheless, the apps quality (aesthetics, functionality, information, and engagement) varies significantly. Many lack supporting RCTs, rigorous evaluation procedures, or published protocols and generally show an absence of quality assessment [40,41]. However, new users still choose to download such apps, and research has shown that user feedback (subjective quality) is more influential in convincing new users to download an app than RCTs and scientific evidence [42]. The correlation between user feedback and app quality is particularly important for new users to choose high-quality apps. Unfortunately, the correlation between user feedback and app quality has not been thoroughly investigated based on previous studies. Furthermore, most research on these apps was conducted before 2020, and previous reviews of apps have tended to focus on pregnant women while disregarding the pre-conception and the postpartum period [43-45]. Finally, some reviews evaluating the information and quality of apps restricted their search to those available in their respective country's app store [44,46-48]. Consequently, many frequently used apps may have been excluded, thereby limiting the conclusions that can be drawn from the results.

Furthermore, online physical training with apps has also been popular in recent years to prevent Covid-19 infection and improve the effectiveness of training away from sports facilities [49]. It may be beneficial for improving maternal physical and mental health, and affordability represents a major advantage of online exercise training program [50]. Online fitness training, particularly high intensity interval training, so called HIIT (brief bouts of vigorous exercise interspersed with intervals of rest or active recovery), has recently attracted the attention of researchers [51]. HIIT has been demonstrated to not only improve cardiovascular function but also significantly increase mitochondrial activity in skeletal muscle, glucose and lipid metabolism, and overall body composition [52]. Performing HIIT during pregnancy is safe in terms of obstetric outcomes and well tolerated by pregnant participants, while providing them with the enjoyment of exercise. HIIT interventions either led to an improvement in selected maternal and fetal health parameters or had no impact. No adverse effects were observed. Pregnant women may benefit from HIIT programs in the same way as other populations. Notably, most studies have involved older adults, women who have already undergone menopause, and pregnant elite athletes [53-55]. However, to date little reliable data have been available on online HIIT performed during pregnancy.

The lack of popularity of HIIT programs for pregnant women may be a consequence of conservative guidelines, issued 30 years ago, suggesting that exercising women should reduce their habitual levels of exertion in pregnancy and refrain from initiating strenuous exercise programs [56]. In the 1990s, it was widely believed that pregnant women should avoid anaerobic training like sprinting or interval work [57]. Such recommendations were based, among others, on the results of scientific studies demonstrating the negative effects of hard physical work, combined with undernutrition, on the development of pregnancy in laboratory animals [58,59]. Fortunately, given the subsequent evidence from the human population about the positive impact of prenatal exercise on maternal and child health, the question is not "if" but "how" pregnant women should exercise [60]. Evidence-based recommendations on online prenatal HIIT should be developed and promoted worldwide among pregnant women, exercise, and health professionals.

3. Critical research gaps

Previous studies found that women were less active when pregnant than in the pre-pregnancy period [61] and that exercise intensity and duration were also reduced [62]. However, the following factors are unclear: (1) the level of prenatal physical activity during the COVID-19 pandemic; (2) how psychological, demographic, and social factors synthetically influence prenatal physical activity; (3) which of these variables are the most prominent in pregnant women during the COVID-19 era; (4) the levels of prenatal physical activity in nonpregnant nulliparous women who may also experience pregnancy complications in the future.

Furthermore, as apps have become essential digital resources for accessing healthcare guidance throughout the pregnancy to postpartum period, increasing amounts of research have been devoted to assessing their quality and efficacy to ensure that women receive appropriate guidance. Based on a review of recent studies of the impact of mHealth on the pregnancy to postpartum period, two results emerged: (1) the importance of mothers receiving accurate health information throughout their children's first 1,000 days of life [63,64] and (2) the major influence of mHealth on maternal well-being, lifestyle, and decision-making about pregnancy and infant health [65]. However, data from RCTs on this subject are still insufficient. Noteworthy gaps in the current research were also exposed. First, the authenticity, quality, and effectiveness of the most recent upgraded content provided by pregnancy to postpartum care apps. Second, whether the apps consider privacy and security issues when collecting personal information and data. Third, the link between user rating and app quality rating has been ignored; as a quick way to judge the quality of an app, user ratings help drive new users to download them [66].

Another area of my research interests was the use of online tools for the implementation of exercise programs for pregnant women, especially in the form of HIIT. Numerous studies have already demonstrated the health benefits of online exercise programs [49,50]. On the other hand, many authors have observed that HIIT programs led to beneficial effects in various populations, including overweight or obese adults [67], populations with cardiac or metabolic disorders [68], elderly people with dementia [69] and cancer patients [70]. Interestingly, promising outcomes of HIIT interventions for the improvement of reproductive functions have been observed both in women [71] and men [56,72] with infertility. However, data on the effectiveness of online HIIT programs in pregnant women are lacking [14].

4. Research objectives

The overall objective of my dissertation was to collect novel data on how to support physical activity and health during pregnancy using online tools. In this work the online tools supporting prenatal physical activity and health were defined as any program, app, or technology that can be accessed via an internet connection and enhance the access to information or service related to a healthy, active lifestyle during pregnancy.

First, I aimed at determining the level of prenatal physical activity in the context of health belief model, with the use of online survey. Secondly, my research objective was to characterize the quality of pre- and postnatal health care mobile apps. Thirdly, I aimed at assessing the effects of online, supervised HIIT intervention on the parameters related to the exercise capacity and anaerobic threshold (AT), body weight, and body composition in pregnant women.

Specific objectives include:

Paper 1: (1) to determine, using the online survey, the health believe level (HBL) and physical activity (PA) among Chinese women who were nonpregnant nulliparous, pregnant nulliparous, and pregnant parous; (2) to examine the demographic factors and health believe model (HBM) dimensions associated with the prenatal physical activity; (3) to predict the characteristics of prenatal physical activity in subgroups in order to determine the best way to increase the level of prenatal physical activity, taking into account the diverse needs of pregnant women.

Paper 2: (1) to describe and analyze the features and functions of mobile apps for pregnancy to postpartum care available in China and the US, two of the largest app markets; (2) to examine the apps' security, quality, and effectiveness; and (3) to provide suggestions for future development and usage of mobile apps for pregnancy to postpartum care of mothers and children.

Paper 3: (1) to describe and analyze the characteristics and functional modules of pregnancy to postpartum nutrition and physical activity (N&PA) apps in the United States and China, two of the largest app markets; (2) to evaluate comprehensively the overall quality of pregnancy to postpartum N&PA mobile apps; and (3) to investigate the connection between app quality rating and user rating.

Paper 4: (1) to evaluate the effects of an 8-week, online HIIT program on selected parameters related to the anaerobic threshold and body composition during pregnancy; and (2) to examine the relationship between the characteristics of the online exercise intervention and changes in the selected parameters related to the anaerobic threshold and body composition.

5. The summary of the papers included in the dissertation

5.1. Paper 1

In **paper 1**, with my research team, we elucidated the precise effect of each moderator variable on prenatal physical activity by examining demographic factors, the prenatal physical activity-related HBL, and the current prenatal physical activity level. The HBM in conjunction with the online questionnaire of international prenatal physical activity questionnaire was used. Data were collected using professional online questionnaire survey technology (WenJuanXin). A link or quick-response (QR) code for the electronic questionnaire was created to make it easier for participants to scan the code and complete it on their smartphone. 414 participants were Chinese citizens (100%); 202 (48.9%) aged 26 to 34; 259 (62.5%) were of Han nationality; 141 (34.1%) were living in urban areas; pregnant nulliparous women (42.6%) and pregnant parous women (57.4%), of whom 34.2% were in the third trimester. This research examined prenatal physical activity levels in nulliparous and parous pregnancies during the ongoing COVID-19 pandemic. Additionally, HBL was investigated in women of different socioeconomic levels, placing emphasis on reproductive-age women who had not given birth. The correlation between physiological factors and HBL and prenatal physical activity was verified. Based on HBM, this study offers much-needed information on changes in the moderators, individual perceptions, and the energy expenditure of prenatal physical activity performed by pregnant women. We then used a regression tree to estimate the energy expenditure of PA, which may enable the creation of intervention strategies, given that these variables may have varied effects depending on geography, economy, and culture.

Main outcomes from **Paper 1**: the HBL score in pregnant parous women was significantly higher than that in nonpregnant nulliparous women (3.42 v. 3.06, respectively; $p < 0.05$); the prenatal physical activity level in the pregnant nulliparous women was lower than in the pregnant parous women (5.67 vs 6.01, respectively; metabolic equivalent-hours per week-MET-h/week) (**Figure 1**); all HBM dimensions (except for perceived barriers) were positively correlated with exercise energy expenditure in both pregnancy nulliparous women and pregnancy parous women; according to the regression tree, participants in pregnancy nulliparous women aged ≤ 23 years with annual household incomes > CNY 100,001–150,000 had the highest energy expenditure (10.75 MET-h/week), whereas participants in pregnancy parous women with a perceived benefit score of > 4 had the highest energy expenditure (10 MET-h/week). The results demonstrated that the HBL in all groups was acceptable, whereas the prenatal physical activity level was lower than the recommended PA level.

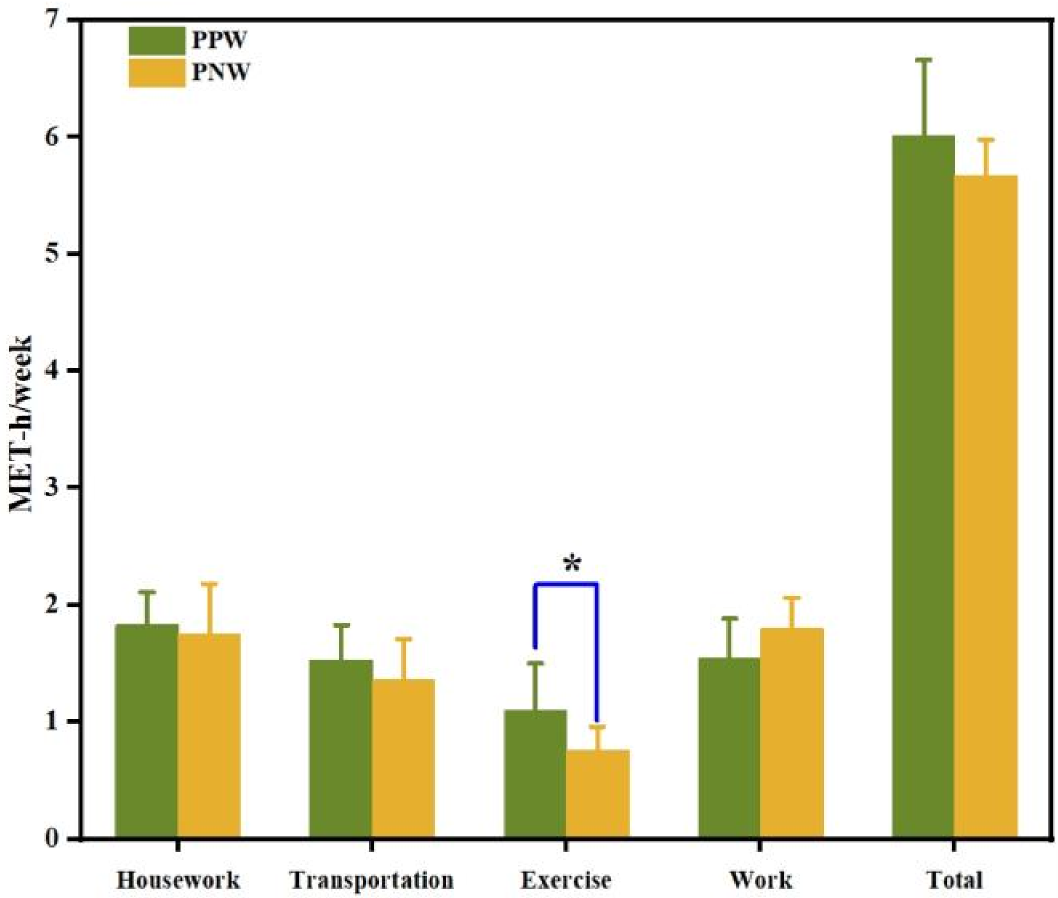

Figure 1. Mean difference in physical activity expenditure between pregnant nulliparous and pregnant parous women. Note: MET-h/week: metabolic equivalent-hours per week; PPW: pregnant parous women; PNW: pregnant nulliparous women; * $p < 0.05$.

5.2. Paper 2

In **Paper 2**, we employed the Mobile Application Rating Scale (MARS) to evaluate app quality through four dimensions of objective app quality, including engagement, functionality, aesthetics, and information quality [73]. The MARS, a reliable, multi-dimensional, simple, and objective tool, was thus developed to classify and evaluate the quality of mobile health apps. Apps were selected by searching the Apple App Store and Android Markets (in the US and China) for the terms "pregnancy" and "postpartum" in Chinese and English. A total of 84 mobile pregnancy to postpartum care apps (45 from the US and 39 from China) were included. The apps' security, quality, and effectiveness were investigated, and chi-square tests and analysis of variance were performed to examine the differences in characteristics between apps available in the US and China. To the best of our knowledge, this study is the first to evaluate the quality and risks associated with in-store pregnancy to postpartum care apps in China and the US. Second, we acted as users at various pregnancy to postpartum stages to download and utilize the apps, which may or may not have resulted in overlooking functional information about the mobile apps. Third, the consistency and dependability of the data gathered were rigorously evaluated before being used.

Main outcomes from **Paper 2**: a total of 89.7% (35/39) of Chinese mobile apps did not provide safety statements or supporting evidence (**Table 1**); the objective app quality ratings for Chinese and US apps were 3.20 ± 0.48 (mean ± standard deviation) and 3.56 ± 0.45, respectively ($p > 0.05$); a greater number of Chinese apps provided app-based monitoring functions, namely recording fetal size (n = 18, 46.2% in China vs. n = 3, 6.7% in the US), contractions (n = 11, 28.2% in China vs. n = 0, 0% in the US), pregnancy weight (n = 11, 28.2% in China vs. 0, 0% in the US), and pregnancy check-up reminders (n = 10, 25.6% in China vs. n = 0, 0% in the US); a greater number of US apps provided exercise modules, namely pregnancy yoga (n = 2, 5.1% in China vs. n = 21, 46.7% in the US), pregnancy workouts (n = 2, 5.1% in China vs. n = 13, 28.9% in the US), and pregnancy meditation (n = 0, 0% in China vs. 10, 22.2% in the US) ($p < 0.01$); a medium security risk was identified for 40% (18/45) of apps in the US and 82.1% (32/39) of apps in China ($p < 0.01$) (**Table 2**). The functionality and characteristics of in-store mobile apps for pregnancy to postpartum care varied between China and the US. Both countries' apps, particularly Chinese apps, encountered issues related to a lack of evidence-based information, acceptable content risk, and program evaluations. Both countries' apps lacked proper mental health care functions.

Table 1. Characteristics of the 84 apps for pregnancy to postpartum care identified in the US–China comparison

Category	China (n = 39)	United States (n = 45)	χ^2/F	p
Specifications, n (%)				
Medical	4 (10.3)	6 (13.3)		
Health and fitness	31 (79.4)	39 (86.7)	1.158	$p > 0.05$[2]
NA[4]	4 (10.3)	0 (0)		
Acquisition costs, n (%)				
Free	26 (66.7)	6 (13.3)		
In-app purchase	13 (33.3)	39 (86.7)	25.200	$p < 0.01$**[2]
Target users (app description accompanying a clear statement), n (%)				
Women TTC[1]	18 (46.2)	6 (13.3)		
Pregnant women	28 (71.8)	32 (71.1)		
Postpartum women	16 (41)	23 (51.1)		
Those providing infant care	16 (41)	1 (2.2)	13.694	$p < 0.05$*[2]
Not specified	3 (7.7)	2 (4.4)		
Safety statement, n (%)				
With	4 (10.3)	24 (53.3)		
Without	35 (89.7)	21 (46.7)	17.446	$p < 0.01$**[2]
Privacy policy, n (%)				
With	35 (89.7)	42 (93.3)		
Without	4 (10.3)	3 (6.7)	0.039	$p > 0.05$[2]
Supporting evidence, n (%)				
With	4 (10.3)	23 (51.1)		
Without	35 (89.7)	22 (48.9)	15.988	$p < 0.01$**[2]
Operating system, n (%)				
iOS	29 (74.3)	33 (73.3)		
Android	31 (79.5)	14 (31.1)	26.820	$p < 0.01$**[2]
Year of the most recent update, n (%)				
2020	10 (25.6)	17 (37.8)		
2021	29 (74.4)	28 (62.2)	1.411	$p > 0.05$[2]
Language, n (%)				
Chinese	22 (56.4)	0		
English	0	36 (80)	63.562	$p < 0.01$**[2]
Multiple languages offered	17 (43.6)	9 (20)		
Mean user rating (stars/5)	3.09 ± 0.70	3.41 ± 0.9	3.198	$p > 0.05$[3]

[1]Trying to conceive; [2]chi-square test; [3]analysis of variance; [4]not available; **: extremely significant difference at $p < 0.01$; *: significant difference at $p < 0.05$.

Table 2. The risk assessment of pregnancy and postnatal care mobile apps in the US and China

Risk	United States (n = 45), n (%)	China (n = 39), n (%)	*p*-Value
Low	23 (51.1)	4 (10.3)	$p < 0.01$**
Medium	18 (40)	32 (82.1)	$p < 0.01$**
High	4 (8.9)	3 (7.6)	$p > 0.05$

**: extremely significant correlation at $p < 0.01$; *: significant correlation at $p < 0.05$.

5.3. Paper 3

In the study presented in **Paper 3**, we included 65 maternity-related nutrition and physical activity apps (34 from China and 31 from the United States). We used MARS to assess app quality across four dimensions: engagement (five items), functionality (four items), aesthetics (three items), and information quality (seven items) [73]. A systematic search was performed in Android and iOS app stores (China and the United States). Apps were eligible if they targeted pregnant or postpartum women, focused on nutrition or physical activity (N&PA), and had interfaces in English or Chinese. The basic characteristics, functional modules, and overall quality of the apps were evaluated, and differences between apps available in China or the United States were determined using analysis of variance and chi-square tests. Pearson correlations were utilized to investigate the links between objective quality and user ratings. This research is the first to examine the link between user ratings and app quality associated with in-store pregnancy to postpartum N&PA apps in the United States and China. We behaved as users at different pregnancy to postpartum periods to gather data and ensure we did not miss critical information. Considering the influence of researcher's subjective perception, the reliability of the data collected by the six researchers was examined using the Fleiss Kappa value.

Main outcomes from **Paper 3:** among included apps, 68% (21/31) of US apps and 56% (19/34) of Chinese apps did not provide supporting evidence for their content; a greater number of Chinese apps provided app-based general education modules, namely food nutrition knowledge (n = 0, 0% in the United States vs. n = 30, 88.2% in China). What is more, a greater number of US apps provided exercise modules, namely pregnancy yoga (n = 21, 67.7% in the United States vs. n = 2, 5.9% in China); the overall app quality rating in the United States was lower than it was in China (mean: 3.5, SD: 0.6 in China vs. mean: 3.4, SD: 0.7 in the United States) (**Figure 2**); there was no relationship between the overall app quality rating and the user rating in either country (rho = 0.11 in China and rho = –0.13 in the United States) (**Figure 3**). The characteristics and functional modules of in-store apps for maternal nutrition and physical activity differed between the United States and China. Both countries' apps, especially Chinese apps, lacked evidence-based information, and there was no correlation between app quality and user rating.

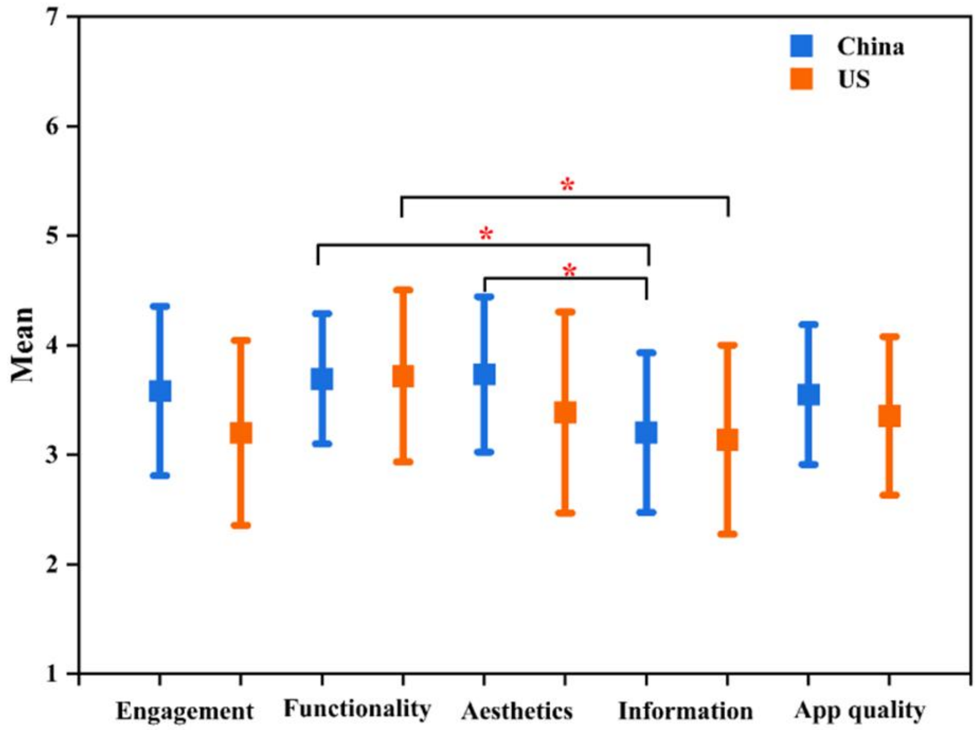

Figure 2. Mean difference in the engagement, functionality, esthetics, information, and overall app quality scores between included apps from the United States and China. *$p < 0.05$.

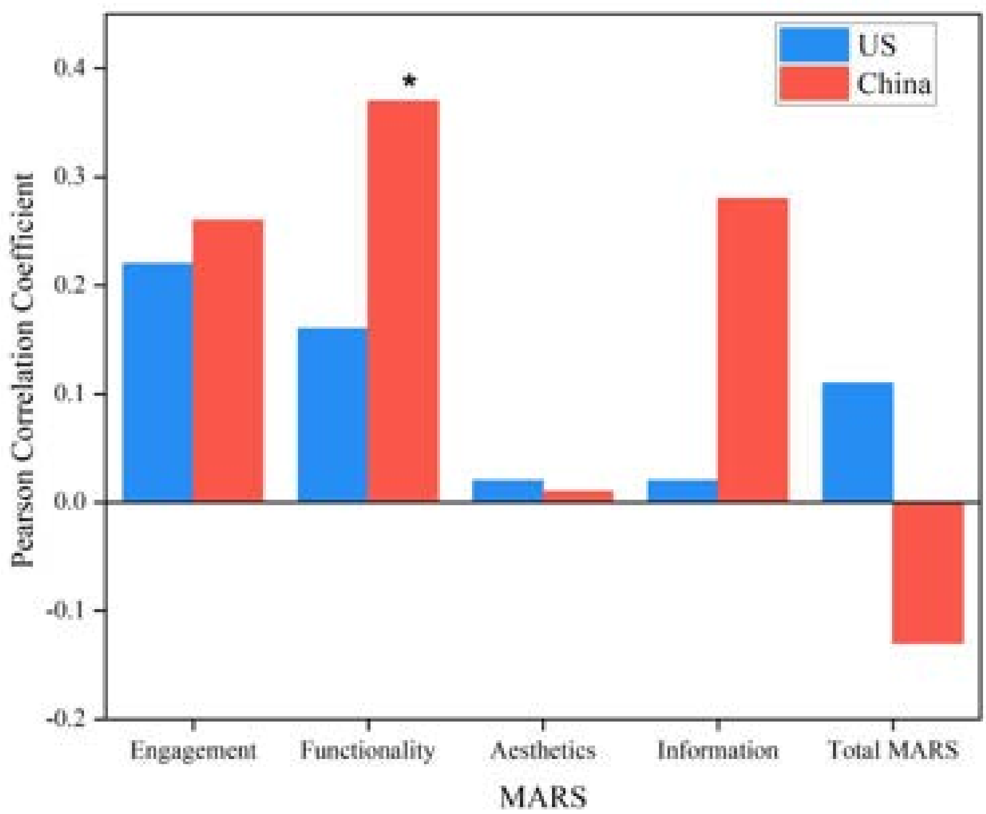

Figure 3. The bar chart illustrates the Pearson coefficients between Chinese and United States mobile app quality rating, four dimensions rating of app quality, and user rating. The Pearson coefficients' maximum positive and negative limits are indicated above and below the origin line at zero. *$p < 0.05$.

5.4. Paper 4

In **paper 4**, we assessed the effects of an 8-week, online HIIT program on the parameters related to the AT, body weight, and body composition in pregnant women. A total of 69 Caucasian women with an uncomplicated singleton pregnancy (age: 31 ± 4 years; gestational age: 22 ± 5 weeks; mean ± standard deviation) were allocated to either an 8-week HIIT program (HIIT group) or to a comparative 8-week educational program (EDU group).

Before and after the intervention all participants underwent cardiopulmonary exercise test up to refusal (CPET) using a cycle ergometer with an electronically regulated load (Viasprint 150P; Bitz, Germany) and a pulmonary gas analyzer (Oxycon Pro; Erich Jaeger GmbH, Hoechberg, Germany) [74]. We analyzed the following parameters: volume of oxygen at the anaerobic threshold (VO_2/AT), heart rate at the anaerobic threshold (HR/AT), percentage of maximal oxygen uptake at the anaerobic threshold (%VO_{2max}/AT), time between the HR/AerT (anerobic threshold) and HR/AT (time during the CPET from the moment when the aerobic capacity was fully used to the threshold when anaerobic exercise started to dominate), and time above the HR/AT (time from the moment when anaerobic exercise started to dominate up to exhaustion and termination of the test).

Additionally, before and after the HIIT and EDU interventions, we used the bioimpedance method with the InBody 720 equipment to record and analyze the body composition, including body weight, body mass index (BMI), total fat mass percentage and total fat-free mass percentage.

The HIIT sessions were held online through MS Teams from 9:30 a.m. to 10:30 a.m. on Mondays, Wednesdays, and Fridays except for one Monday that was a holiday (23 sessions in total) (**Figure 4**). The educational intervention focused on a healthy lifestyle, physical exercise throughout the perinatal period, and specific issues in pregnancy and parenthood (**Figure 4**). To our knowledge, this was the first study to assess the effects of an online HIIT program on parameters related to the AT and body composition of women with uncomplicated pregnancies.

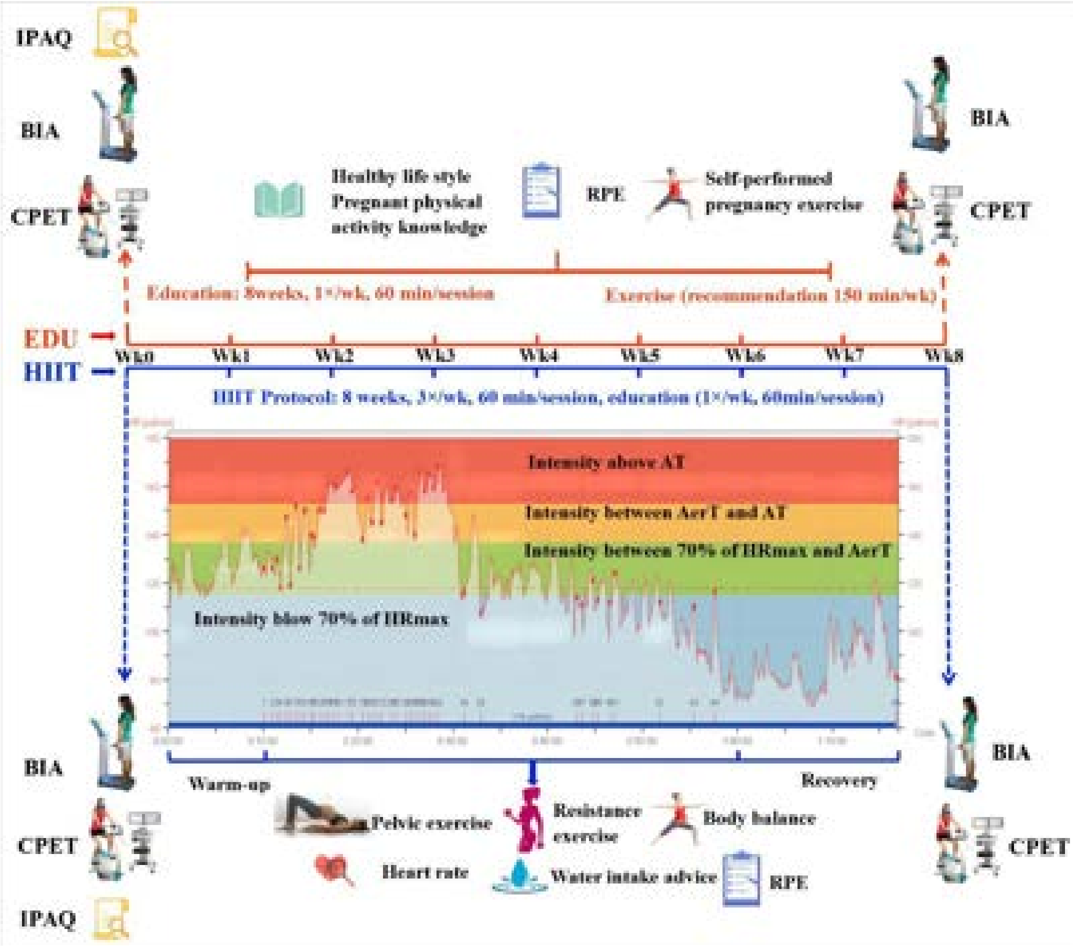

Figure 4. Schematic representation of the study protocol. AerT: aerobic threshold, AT: anaerobic threshold, BIA: bioelectrical impedance analysis, CPET: cardiopulmonary exercise test, EDU: education, HIIT: high-intensity interval training, HRmax: maximal heart rate, IPAQ: International Physical Activity Questionnaire, RPE: rating of perceived exertion.

Our most important finding of **Paper 4** was that even with the 8-week progression of pregnancy and physiological weight gain, the HIIT group maintained the same level of parameters related to AT: volume of oxygen at the AT (VO_2/AT), percentage of maximal oxygen uptake at the AT (%VO_{2max}/AT), and heart rate at the AT (HR/AT) (**Figure 5**). In contrast, in the control group we observed a substantial deterioration in parameters related to the AT (**Figure 5**). The HIIT intervention substantially reduced the fat mass percentage (median: 30% to 28%; $p < 0.01$) and improved the total fat-free mass percentage (median: 70% to 72%; $p < 0.01$) (**Figure 6**). In both group the increase of body weight and BMI was in normal range, typical for the progression of pregnancy.

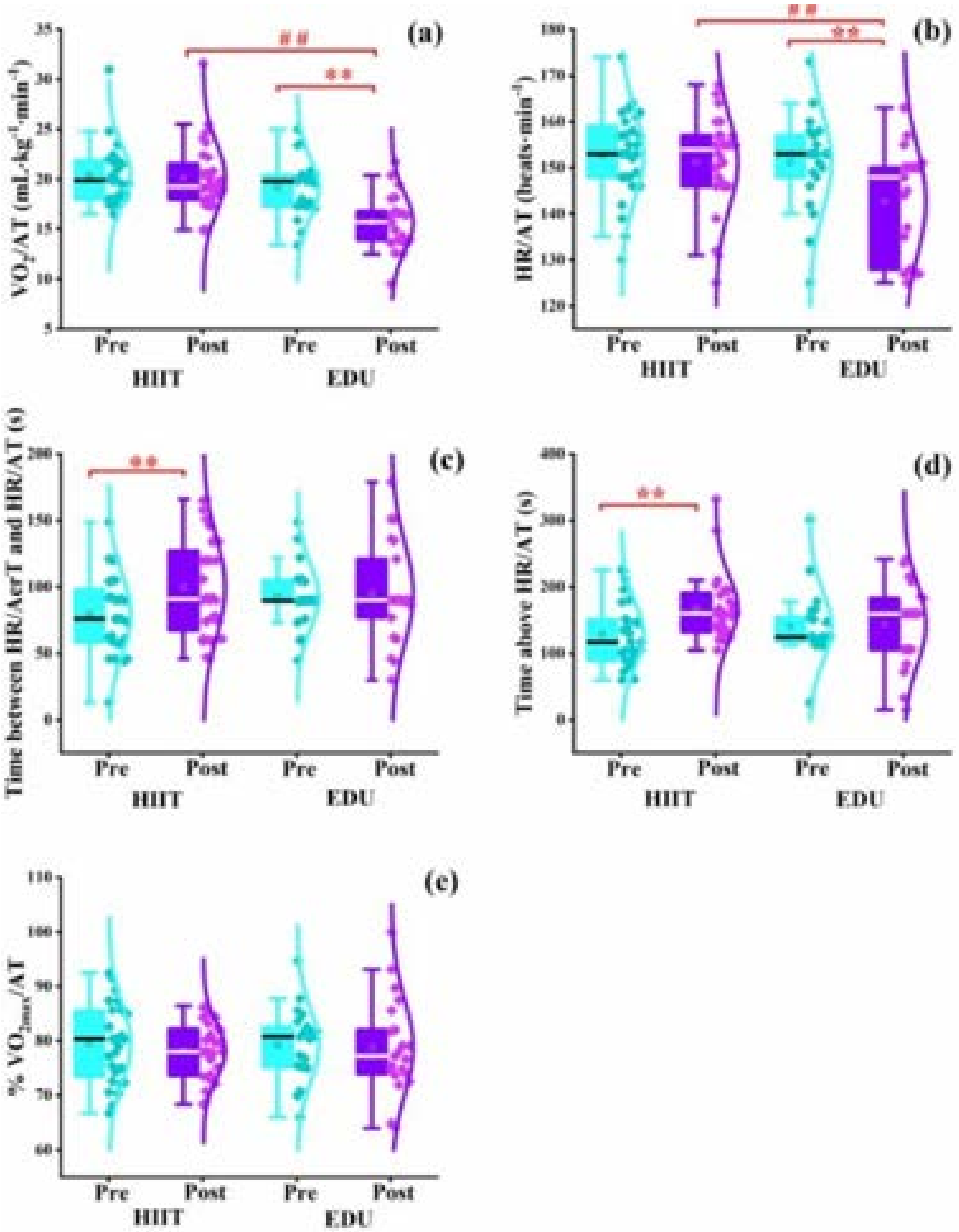

Figure 5. Box charts (a–e) showing the entire distribution of raw data (rhombus) and the median value (central line) of the parameters related to the anaerobic threshold before and after the 8-week HIIT (n = 28) and educational interventions (n = 21). EDU: education, HIIT: high-intensity interval training, HR/AerT: heart rate at the aerobic threshold, HR/AT: heart rate at the anaerobic threshold, VO_2/AT: maximal oxygen uptake at anaerobic threshold, %VO_{2max}/AT: percentage of maximal oxygen uptake at the anaerobic threshold. Data were analyzed using one-way ANOVA (## $p < 0.01$) and a paired Wilcoxon test (** $p < 0.01$).

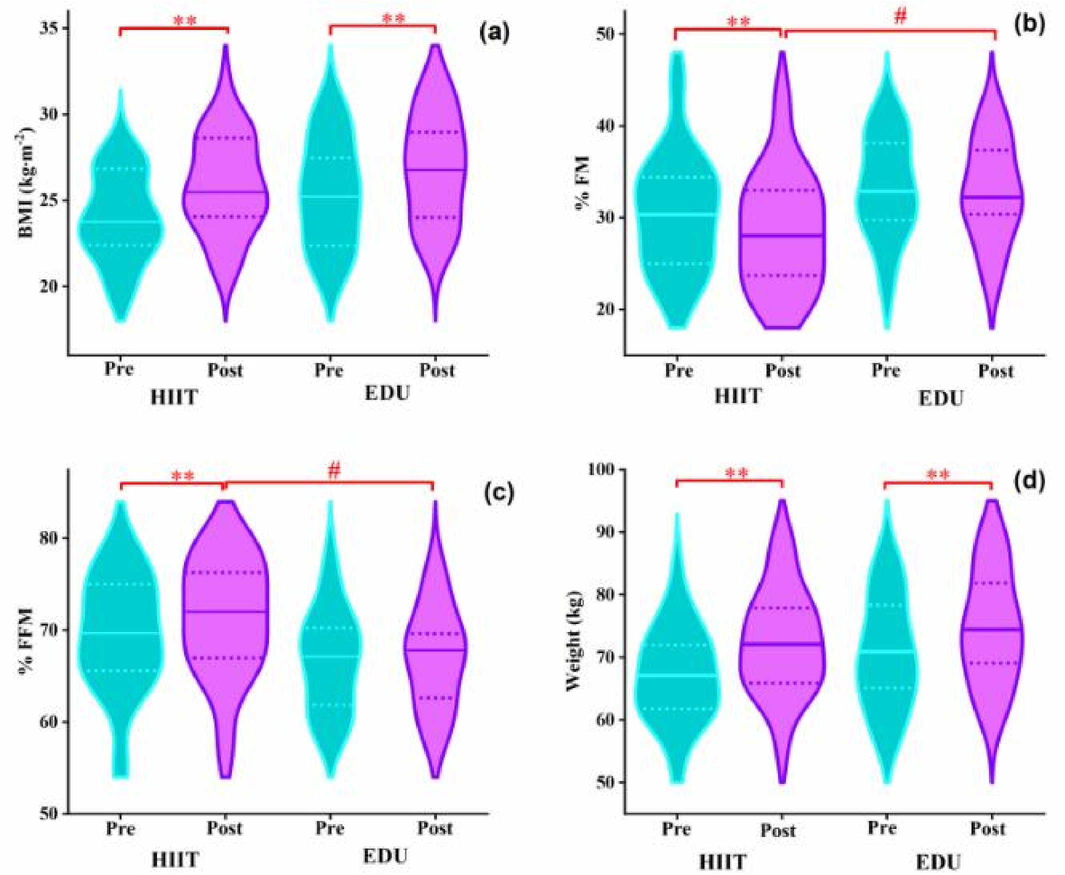

Figure 6. Violin plots (a–d) showing the entire distribution of the median (central line) and interquartile range (lower and upper lines) of the body composition before and after 8 weeks of the HIIT and educational interventions. BMI: body mass index, EDU: education, HIIT: high-intensity interval training, %FFM: fat-free mass percentage, %FM: fat mass percentage. Data were analyzed using one-way ANOVA (# $p < 0.01$) and a paired Wilcoxon test (** $p < 0.01$).

The online mode of provision of our interventions (both HIIT and educational) may serve as solutions to maintain a sufficient level of physical activity in pregnant women during future lockdowns as during the COVID-19 pandemic. Outside the pandemic period, the online provision of HIIT programs can be a good solution for pregnant women who have limited access to sport facilities, who lack the time to travel to the gym, or who need to stay home (e.g., due to family reasons, including taking care of older children).

6. Key results and conclusions from individual papers

In **Paper 1**, we found: (1) all HBM dimensions (perceived susceptibility, perceived severity, health motivation, perceived benefits, self-efficacy, and cues to action) had a positive relationship with exercise energy expenditure in both pregnant nulliparous women and pregnant parous women, except for perceived barriers; (2) the predicted prenatal physical activity would meet the recommended level in young pregnant nulliparous women with high incomes; perceived benefits directly affected the prenatal physical activity value in the pregnant parous group; (3) the prenatal physical activity level was lower than the recommended PA level.

These findings confirm that different strategies should be implemented in different subgroups of women to increase their level of prenatal physical activity, taking into account the diverse characteristics and behaviors patterns. The use of online surveys, although has some limitations, can support the process of recognizing women's needs and expectations.

In **Paper 2** and **Paper 3**:

We found that functionality and characteristics of in-store mobile apps for pregnancy to postpartum care varied between China and the US; (2) in both countries' apps, particularly Chinese apps, we noted issues related to a lack of evidence-based information, acceptable content risk, and program evaluations; (3) the characteristics and functional modules of in-store apps for maternal nutrition and physical activity differed between the United States and China, and the total MARS score was not correlated with the user rating.

The results therefore suggest that user ratings cannot be treated as an objective indicator of app quality and that it is necessary to improve the empirical basis and credibility of apps in both countries. Women's basic public health-related services should be supported through the creation of highly effective pregnancy and postpartum mobile apps. However, effective monitoring of information provided in mobile apps is required to ensure their quality. There is a need to evaluate the quality of mobile apps for pregnant and postpartum women available in other countries and languages.

In **Paper 4**:

An 8-week online HIIT program had a positive impact on the exercise capacity and the body composition in women with uncomplicated pregnancies without producing adverse obstetric and neonatal effects. Our findings indicated that online, supervised HIIT combined with education on a healthy lifestyle during pregnancy had a greater impact on health parameters than education alone. This online protocol can potentially promote exercise programs during the COVID-19 pandemic and in situations where women have limited time or access to sport facilities. Evidence-based recommendations on online, prenatal HIIT should be developed and promoted worldwide among pregnant women, exercise, and health professionals.

7. Limitations of the studies and future research directions

Some of limitations should be addressed in this dissertation before evaluating the conclusions. For instance, the sample consisted of nonpregnant and pregnant women who were available and willing to participate from China's central and western regions in the **Paper 1**. Thus, the results may not be generalizable to pregnant women residing in other parts of China, such as large metropolitan regions, or to ethnic minorities. Second, only self-reported measurements were used to assess prenatal physical activity levels due to the prohibitive cost and practical difficulty of objectively assessing prenatal physical activity levels (e.g., using accelerometers) in such a large group of respondents. Third, this research only gathered cross-sectional data, making it impossible to draw conclusions about longitudinal changes in individual activity levels. Longitudinal studies that investigate PA before and during pregnancy in a population-based sample are suggested for the future.

In **Paper 2** and **Paper 3,** we reviewed the apps at a single time point. This means we may have ignored modifications to app functionality over the long term. Second, we also removed paid apps without free trials, which could have prevented us from accessing all the available information. Third, the possibility of evaluation bias should be acknowledged. Although app quality was independently assessed by six researchers and agreement was high, it is possible that ratings were subject to individual preference. Finally, a language barrier prevented us from including apps from other countries. Future investigators may seek to examine other time periods to produce longitudinal comparisons of functional modules and quality across a larger number of countries.

In **Paper 4**, we only recruited pregnant women of a single ethnicity to minimize the degree of heterogeneity among the participants. Despite being likely representative of a demographic and socially similar population, the findings may be limited in their application to other races. Second, no information regarding dietary intake was obtained. In pregnant women, protein supplementation may enhance the beneficial effects of HIIT. Another weak point of our work was that we did not compare our intervention to other online exercise programs or programs implemented at the gyms in the direct contact with the trainer. Certainly, our educational group seemed to be an interesting comparative group because it represented pregnant women under standard obstetric care. In accordance with current guidelines, all pregnant women should obtain information on a healthy lifestyle, including physical activity, from their obstetric care providers. However, the comparison of the effectiveness of online prenatal HIIT to an online moderate-intensity continuous program would be very valuable. Further research is needed to investigate the above-mentioned issues.

8. General conclusions from the dissertation

In summary, despite the limitations described above, my dissertation on "Physical activity and health in pregnancy and the use of online tools" seems to be important for popularizing a healthy, active life among pregnant women. In individual papers, together with co-authors, we showed that online tools can support the process of recognizing pro-health behaviours of pregnant women thanks to the wide range of online surveys. This may be useful for the individualization of strategies supporting physical activity in groups of women with different models of health behaviour and with different socio-geographical characteristics. Online tools also enable the effective implementation of exercise programs, including high-intensity exercise programs, as well as educational interventions related to a healthy lifestyle. Nevertheless, there are also risks associated with online tools, e.g., mobile applications and the information presented in them, which is not evidence-based. Therefore, supporting physical activity and health of pregnant women using online tools should be a well-thought-out and qualitatively verified process. If so, online tools can be effective, safe, accessible, and integrated into policy and practice. This can help to improve the health and well-being of pregnant women and their babies.

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Abstract

According to current recommendations, including the World Health Organization, physical activity during pregnancy is essential for proper course of pregnancy and child development. There is a lot of scientific evidence that physical inactivity may cause both short- and long-term health issues for pregnant women and their offspring. However, most women remain inactive or are insufficiently active during pregnancy. Therefore, any evidence-based information, reinforcing strategies to promote prenatal physical activity is necessary.

The overall objective of my dissertation was to collect novel data on how to support physical activity and health during pregnancy using online tools. First, I aimed at determining the level of prenatal physical activity in the context of health belief model, with the use of online survey (Paper 1). Secondly, my research objective was to characterize the quality of pre- and postnatal health care mobile apps (Paper 2 and Paper 3). Thirdly, I aimed at assessing the effects of online, supervised HIIT intervention on the parameters related to the exercise capacity and anaerobic threshold, body weight, and body composition in pregnant women (Paper 4).

In Paper 1, we surveyed 414 women, aged 20-35 years, using an online questionnaire based on the health belief model (HBM) and the international prenatal physical activity questionnaire. The prenatal physical activity (PA) level was lower than the recommended by WHO. Most HBM dimensions (perceived susceptibility, perceived severity, health motivation, perceived benefits, self-efficacy, and cues to action) had a positive relationship with exercise energy expenditure in both pregnant nulliparous women and pregnant parous women. Perceived benefits directly affected the prenatal physical activity level in the pregnant parous group. These findings confirm that different strategies should be implemented in different subgroups of women to increase their level of prenatal physical activity, taking into account the diverse characteristics and behaviors patterns.

In the next two papers we evaluated the quality of pregnancy to postpartum care mobile applications in terms of engagement, functionality, aesthetics, and information quality, using the Mobile Application Rating Scale (MARS). A total of 84 mobile pregnancy to postpartum care apps (45 from the US and 39 from China) were included in the Paper 2. In the Paper 3 we included 65 maternity-related nutrition and physical activity apps (34 from China and 31 from the United States). We found that functionality and characteristics of in-store mobile apps for pregnancy to postpartum care varied between China and the US. Importantly, in both countries' apps, particularly Chinese apps, we noted issues related to a lack of evidence-based information, acceptable content risk, and program evaluations. What's more and the app quality was not correlated with the user rating. The results therefore suggest that user ratings cannot be treated as an objective indicator of app quality and that it is necessary to improve the empirical basis and credibility of apps in both countries.

In paper 4, we assessed the effectiveness of an 8-week, online HIIT program. A total of 69 Caucasian women with an uncomplicated singleton pregnancy (age: 31 ± 4 years; gestational age: 22 ± 5 weeks; mean ± standard deviation) were allocated to either an 8-week HIIT program (HIIT group) or to a comparative 8-week educational

program (EDU group). Before and after the intervention all participants underwent cardiopulmonary exercise test up to refusal using a cycle ergometer and a pulmonary gas analyzer. Additionally, we used the bioimpedance method and analyze participants' body composition. The online HIIT program had a positive impact on the exercise capacity and the body composition without producing adverse obstetric and neonatal effects. This online protocol can potentially be promoted during the COVID-19 pandemic and in situations where women have limited time or access to sport facilities.

The findings from my dissertation seem to be important for popularizing a healthy, active life among pregnant women. The online tools can support the process of recognizing pro-health behaviours of pregnant women thanks to the wide range of online surveys. Online tools also enable the effective implementation of exercise programs, including high-intensity exercise programs. Nevertheless, there are also risks associated with online tools, e.g., mobile applications and the information presented in them, which is not evidence-based. Therefore, supporting physical activity and health of pregnant women using online tools should be a well-thought-out and qualitatively verified process. If so, online tools can be effective, safe, accessible, and integrated into policy and practice targeted into promotion of prenatal physical activity. This can help to improve the health and well-being of pregnant women and their babies.

Streszczenie

Według aktualnych zaleceń, w tym Światowej Organizacji Zdrowia, aktywność fizyczna w ciąży jest niezbędna dla prawidłowego przebiegu ciąży i rozwoju dziecka. Istnieje wiele naukowych dowodów na to, że brak aktywności fizycznej może powodować zarówno krótko-, jak i długoterminowe problemy zdrowotne kobiet w ciąży, jak i ich potomstwa. Jednak większość kobiet pozostaje nieaktywna lub jest aktywna w niewystarczającym stopniu podczas ciąży. Dlatego konieczne są wszelkie informacje oparte na dowodach, wzmacniające strategie promujące prenatalną aktywność fizyczną.

Ogólnym celem mojej pracy doktorskiej było zebranie nowych danych na temat sposobów wspierania aktywności fizycznej i zdrowia podczas ciąży za pomocą narzędzi internetowych. W pierwszej kolejności postawiłam sobie za cel określenie poziomu prenatalnej aktywności fizycznej w kontekście modelu przekonań zdrowotnych, z wykorzystaniem ankiety internetowej (Publikacja 1). Po drugie, moim celem badawczym było scharakteryzowanie jakości aplikacji mobilnych wspierających zachowania zdrowotne w okresie okołoporodowym (Publikacja 2 i Publikacja 3). Po trzecie, moim celem była ocena wpływu nadzorowanej interwencji HIIT zrealizowanej w formie online na parametry związane z możliwościami wysiłkowymi, progiem przemian beztlenowych, masą ciała i składem ciała u kobiet w ciąży (Publikacja 4).

W publikacji 1 przebadaliśmy 414 kobiet w wieku 20-35 lat za pomocą kwestionariusza internetowego opartego na modelu przekonań zdrowotnych (Health Belief Model - HBM) i międzynarodowego kwestionariusza prenatalnej aktywności fizycznej. Poziom aktywności fizycznej w okresie prenatalnym był niższy u badanych kobiet niż zalecany przez WHO. Większość wymiarów HBM miała pozytywny związek z wartością wydatku energetycznego determinowanego ćwiczeniami, zarówno u nieródek, jak i u kobiet po przebytych porodach. W grupie kobiet ciężarnych, postrzegane korzyści z ćwiczeń w ciąży bezpośrednio wpływały na ich poziom aktywności fizycznej. Wyniki te potwierdzają, że w różnych podgrupach kobiet należy wdrażać odmienne strategie zwiększania poziomu ich aktywności fizycznej w okresie prenatalnym, biorąc pod uwagę zróżnicowane cechy demograficzne i wzorce zachowań.

W kolejnych dwóch publikacjach dokonaliśmy oceny jakości aplikacji mobilnych, kierunkowanych dla okresu ciąży i po porodzie. Aplikacje zostały ocenione pod względem, możliwości zaangażowania użytkownika, funkcjonalności, estetyki i jakości informacji, za pomocą Skali Oceny Aplikacji Mobilnych (MARS). W publikacji 2 zostały uwzględnione łącznie 84 aplikacje mobilne wspierające zachowania zdrowotne w okresie okołoporodowym (45 z USA i 39 z Chin). Zaobserwowaliśmy, że funkcjonalność i charakterystyka aplikacji mobilnych, dostępnych w sklepach internetowych, różniły się w zależności od kraju. Co ważne, w aplikacjach obu krajów, zwłaszcza w aplikacjach chińskich, zauważyliśmy defekty związane z brakiem informacji opartych na dowodach naukowych, akceptowanym wysokim ryzykiem słabej jakości prezentowanych treści i niską oceną zawartych w aplikacjach programów wspierających zdrowie. Co więcej, jakość aplikacji uzyskana

w naszych analizach nie była skorelowana z oceną użytkowników. Wyniki sugerują zatem, że oceny użytkowników nie mogą być traktowane jako obiektywny wskaźnik jakości aplikacji i że konieczna jest poprawa bazy empirycznej i wiarygodności aplikacji w obu krajach.

W publikacji 4 oceniliśmy efektywność 8-tygodniowego programu HIIT, realizowanego w formie online. Łącznie 69 kobiet rasy kaukaskiej z niepowikłaną ciążą pojedynczą (wiek: 31 ± 4 lata; wiek ciążowy: 22 ± 5 tygodni; średnia ± odchylenie standardowe) zostało przydzielonych do 8-tygodniowego programu HIIT (grupa HIIT) lub do grupy porównawczej, uczestniczącej w 8-tygodniowym programie edukacyjnym (grupa EDU). Przed i po interwencji wszystkie uczestniczki wykonały próbę wysiłkową do odmowy z wykorzystaniem ergometru rowerowego i analizatora gazów oddechowych. Dokonaliśmy również analizy składu ciała metodą impedancji bioelektrycznej. Internetowy program HIIT pozytywnie wpłynął na możliwości wysiłkowe i skład ciała, nie powodując niekorzystnych skutków na przebieg ciąży i stan zdrowia noworodków. Tego typu programy ćwiczeń prowadzone zdalnie potencjalnie mogą być promowane w czasie pandemii COVID-19 oraz w sytuacjach, gdy kobiety mają ograniczony czas lub dostęp do obiektów sportowych.

Wnioski z mojej rozprawy wydają się być istotne dla popularyzacji zdrowego, aktywnego trybu życia wśród kobiet w ciąży. Narzędzia internetowe mogą wspierać proces rozpoznawania zachowań prozdrowotnych kobiet w ciąży dzięki szerokiemu zasięgowi. Narzędzia internetowe umożliwiają również skuteczną realizację programów ćwiczeń, w tym programów ćwiczeń o wysokiej intensywności. Niemniej jednak istnieją również zagrożenia z nimi związane, m.in. z użytkowaniem aplikacji mobilnych i prezentowanych w nich informacji, które często nie są oparte na naukowych dowodach. Dlatego wspieranie aktywności fizycznej i zdrowia kobiet w ciąży za pomocą narzędzi internetowych powinno być procesem przemyślanym i zweryfikowanym jakościowo. Jeśli ten warunek zostanie spełniony, narzędzia internetowe mogą być skuteczne, bezpieczne i jednocześnie zintegrowane z polityką i praktyką promowania aktywności fizycznej w ciąży. Może to istotnie przyczynić się do poprawy zdrowia i samopoczucia kobiet w ciąży i ich dzieci.

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Projects:

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Article

Pregnancy Activity Levels and Impediments in the Era of COVID-19 Based on the Health Belief Model: A Cross-Sectional Study

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Abstract: Physical activity (PA) and exercise benefit both the mother and the fetus. Many pregnant women avoid or severely limit PA, leading to complications before and after delivery. This study elucidated the precise effect of each moderator variable on prenatal physical activity (PPA) by examining demographic factors, the PPA-related health belief level (HBL), and the current PPA level. The health belief model (HBM) in conjunction with the international prenatal physical activity questionnaire was used. The HBL in pregnant parous women (PPW) (3.42) was significantly higher than that in nonpregnant nulliparous women (NNW) (3.06). The PPA level in pregnant nulliparous women (PNW) (5.67 metabolic equivalent-hours per week (MET-h/week)) was lower than in the PPW (6.01 MET-h/week). All HBM dimensions (except for perceived barriers) were positively correlated with exercise expenditure in both PNW and PPW. According to the regression tree, participants in PNW aged $\leq$ 23 years with annual household incomes > CNY 100,001–150,000 had the highest energy expenditure (10.75 MET-h/week), whereas participants in PPW with a perceived benefit score of >4 had the highest energy expenditure (10 MET-h/week). The results demonstrated that the HBL in all groups was acceptable, whereas the PPA level was lower than the recommended PA level. In both PPW and PNW, the HBL was most strongly correlated with exercise expenditure. There is an urgent need to organize public-interest courses to alleviate household expenditure, raise the HBL about PPA in pregnant and NNW, and ensure personal health in the context of COVID-19.

Keywords: pregnant women; health belief level; prenatal physical activity; individual perception; health-belief model

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1. Introduction

The World Women's Organization (WWO) was established to defend women's rights in 1947 [1], and the 2030 agenda for sustainable development goal (SDG) 5 points to achieving gender equality and empowering all women and girls, which indicates that women have gained global attention [2]. Pregnancy represents a unique period in a woman's life, and women's health has garnered much attention in the context of women's rights advocacy. Although having children has numerous benefits, women can also face many challenges due to pregnancy, such as obesity, diabetes, nausea (with or without vomiting), discomfort in the pelvic girdle, and other musculoskeletal issues [3].

Studies have demonstrated that being active and leading a healthy lifestyle while pregnant can reduce both the mother's and baby's risk of acquiring chronic diseases [4]. The maternal advantages of exercise include increased fitness; avoidance of excessive pregnancy weight gain, weight retention, and possibly obesity, gestational diabetes, hypertension, and maternal depression [5]; and a decrease in cesarean-section rates [4]. Maternal exercise is also related to healthy birth weight and the prevention of chronic illness in children [6]. Recent studies have shown that maternal physical activity (PA) plays a positive role in the modulation of the progeny's phenotype, giving the offspring improved health potential [3].

The available data unequivocally demonstrate that PA and exercise should be components of a healthy lifestyle for pregnant women. Unfortunately, many pregnant women forego or severely restrict their PA and exercise [6]. The terms of PA and exercise are clarified in this study to understand them correctly. PA is defined as any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in caloric requirements over resting energy expenditure [7,8]. Exercise is a physical activity consisting of planned, organized, and repeated body movement to enhance and maintain one or more components of physical fitness [7] and extend life [9]. Exercise is thus a subcategory of physical activity.

Pregnancy is a memorable life stage that may elicit distinct variables that motivate and impede PA [10]. Pregnant women may want to perform PA for their own health and that of their baby, but they may struggle to do so. Recent studies have revealed that pregnant women tend to be sedentary [10]. Major reasons and factors for this include (1) a lack of desire to be active, which pregnant women often mention as a barrier to exercise [11]; (2) unawareness of the value of prenatal physical activity (PPA), how much exercise is needed, and how to exercise safely [10]; (3) social variables, such as a lack of support from friends, family, and doctors to be active, which can significantly influence PPA levels; and (4) traditional culture, as pregnancy has historically been viewed as a time for relaxation and recuperation [12]. However, these studies have not proposed specific strategies for solving these problems, and the listed reasons and factors may vary by the location, culture, and limitations of the coronavirus disease 2019 (COVID-19)-pandemic era. Health status and geographic location are crucial variables that directly and indirectly impact PPA behavior through other determinants [13]. This is particularly true in China, where the two-child policy is liberalized. As the “two-child” fertility rate rises, barriers may shift as an outcome of this policy [14]. Meanwhile, COVID-19 and its corresponding isolation periods may harm the health of pregnant women and introduce various PPA dilemmas.

Consequently, it is essential to study the variables and obstacles influencing PA among pregnant women in China and explore effective strategies, considering differences in geography, culture, and the prevalence of COVID-19. This study can contribute to health and well-being, equity, quality education, and society safety under the international spotlight [15]. Moreover, it falls within the scope of the UN’s Sustainable Development Agenda 2030. Previous studies found that Chinese women were less active when pregnant than they were before they became pregnant [16] and that exercise intensity and duration also reduced [17]. However, the following factors are unclear: (1) the level of PPA during the COVID-19 pandemic; (2) how psychological, demographic, and social factors synthetically influence PPA; (3) which of these variables are the most prominent in Chinese pregnant women during the COVID-19 era; (4) the cognitive levels of PPA in nonpregnant nulliparous women who may also experience pregnancy complications in the future.

The health belief model (HBM) [18] is a classic and widely used psychological theory in health science that may be employed to determine the most critical factors across geographies, economies, and cultures and shed light on the relationship between psychological, demographic, and social factors and PPA. The HBM defines the key factors that influence health behaviors as an individual’s perceived threat to sickness or disease (perceived susceptibility), belief of adverse consequence (perceived severity), potential positive benefits of action (perceived benefits), perceived barriers to action, exposure to factors that prompt action (cues to action), health motivation, and confidence in ability to succeed (self-efficacy) [18]. The HBM provides a simple method of understanding factors that influence behavior and identifying specific behavior-change techniques that can affect these factors to increase the likelihood that the desired behavior will be enacted [19]. The HBM is an effective tool, which has been successfully applied in health education and health promotion for explaining and promoting preventive health behaviors [19]. Using the HBM, researchers may discover likely methods and resources to improve women’s desire and capacity to engage in or maintain PA throughout pregnancy during the COVID-19 pandemic.

Consequently, using the HBM in conjunction with the international prenatal physical activity questionnaire (PPAQ) [20], the current research focused on the following objectives:

(1) to determine the health belief level (HBL) and PA among Chinese women who are nonpregnant nulliparous, pregnant nulliparous, and pregnant parous; (2) to examine the demographic factors and HBM dimensions associated with the current PPA; (3) to predict the values of PPA, which may be useful in establishing population subgroups in need of intervention in order to determine the best route for increasing the PPA level during COVID-19. On the basis of the above information, we hypothesized that (1) the PPA level would be lower than the recommended PA level during COVID-19; (2) nonpregnant nulliparous women would have lower HBLs than pregnant nulliparous and pregnant parous women; and (3) demographic factors and HBL are correlated with PPA.

2. Materials and Methods

2.1. Study Design and Respondents

It was a cross-sectional study in a convenience sample of nonpregnant nulliparous, pregnant nulliparous, and pregnant parous Chinese women. They were asked to voluntarily participate in the research through an e-questionnaire displayed at five geographically distributed medical practices across several regions in China: Sichuan, Hubei, Shanxi, Chongqing, and Guangdong. Demographic factors, HBM dimensions (perceived susceptibility, perceived severity, health motivation, perceived benefits, perceived barriers, self-efficacy, and cues to action), and PPA levels (only in pregnant nulliparous and pregnant parous women due to the specificity of the PPAQ) were collected in the survey. Prepregnancy PA was not collected from the pregnant participants; consequently, the PA of nonpregnant nulliparous women was not investigated. The inclusion criteria for nonpregnant nulliparous respondents were as follows: 20-to-50-year-old healthy females without contraindications to exercise, nonpregnant nulliparous women, and women with no mental or cognitive problems. For pregnant respondents, the inclusion criteria were as follows: 20 to 50 years old, single pregnancy without contraindications to exercise, no history of recurrent miscarriage or preterm delivery, no early membrane rupture or vaginal hemorrhage, no placenta previa, no severe anemia or other systemic illnesses, and no mental or cognitive problems. The exclusion criteria were as follows: age under 20 years old or over 50 years old, multiple previous pregnancies, current pregnancy with obstetrical and medical illnesses necessitating PA restriction, inability to complete the questionnaire, and refusal to participate in the research. All procedures performed in the study involving human participants were in accordance with the Bioethics Commission at the District Medical Chamber in Gdansk (KB—8/21 and 8/21a). All participants provided written informed consent.

2.2. Materials

2.2.1. Survey Tool

Following the HBM, the researchers created the questionnaire. The survey instrument was created following a thorough examination of both the existing research literature and previously produced questionnaires evaluating pregnant women's demographic factors and HBM dimensions. The PPAQ was also used to determine the pregnant respondents' PA levels. The survey was subsequently pilot tested to assess its content validity and clarity by medical practitioners, academic researchers, and postgraduate students (n = 10) who also provided feedback that contributed to the final version of the instrument. The survey was divided into three parts: participants' demographic features, PPA-related health beliefs, and PPA during pregnancy.

The following were the exact contents of the survey. (1) Demographic variables were collected and evaluated, including the participant's age, combined family income, marital status, education level, job status, and number of children. (2) The PPAQ was created in the United States and is now widely utilized globally. The Chinese version was introduced and translated by Zhang Yan et al. with a 0.940 content validity and 0.944 retest reliability ($p < 0.01$) [20]. This version of the PPAQ contains four domains: housework (14 items), transportation (4 items), occupational activities (8 items), and exercise (5 items). The PPA value in this research was determined using the following energy-expenditure formula: metabolic equivalent (MET)-hours per week = MET coefficient of activity × duration (hours per session) × frequency (times per week) [21]. According to the recommendations of the American College of Obstetricians and Gynecologists (ACOG) regarding PA during pregnancy and postpartum [22], the PPA of 7.5 MET-h/week was deemed a sufficient PPA level in this study. A PPA of less than 7.5 MET-h per week was deemed insufficient [22]. (3) PPA-related HBL was examined using this part of the questionnaire, which included seven dimensions with 27 items according to the HBM (see Table 1 for the specific dimensions and items). The respondents assessed each item on a 5-point Likert scale, in which 5 indicated "strong agreement"; 4 indicated "moderate agreement"; 3 indicated "not sure"; 2 indicated "moderate disagreement"; and 1 indicated "strong disagreement". Scores < 3 represented a poor HBL, scores ≥ 3 and ≤ 4 represented an acceptable HBL, and scores > 4 represented a good HBL. The item related to perceived barriers adopted the reverse-scoring method (i.e., higher scores indicated that fewer obstacles were encountered.). Since the number of items in each dimension varied, the mean score of each dimension (i.e., the score of each dimension/number of items) was computed for ease of comparison, and the exploratory factor analysis (EFA)-weighted score method was used to calculate the weighted HBL scores, with a higher score representing a higher PPA health belief [23].

Table 1. The prenatal physical activity-related health belief model scale.

Dimensions	Item Number	Items	Cronbach's α
Perceived severity (Belief about how serious a condition and its sequelae are)	1	Prenatal physical inactivity is a severe problem.	0.75
	2	Prenatal physical inactivity can lead to complications, such as obesity, gestational diabetes and gestational hypertension, preeclampsia, and urinary incontinence.	
	3	Prenatal physical inactivity can lead to anxiety and depression.	
	4	Prenatal physical inactivity can lead to post-term pregnancy and cesarean section.	
Perceived susceptibility (Belief about the chances of experiencing a risk or acquiring a condition or disease)	5	Pregnant women do not engage in physical activity.	0.91
	6	Fear of miscarriage can lead to prenatal physical inactivity.	
	7	Some habits can cause prenatal physical inactivity, including disinterest, indolence, and busyness.	
	8	Financial burdens, inadequate equipment, and lack of professional guidance can cause prenatal physical inactivity.	
	9	Recommendations from family members, doctors, and other pregnant women can cause prenatal physical inactivity.	
Health motivation (Awareness of prevention of a risk, condition, or disease)	10	I usually value my health and fetal health.	0.78
	11	I usually take the initiative to acquire prenatal physical activity knowledge.	
Perceived benefits (Belief in the efficacy of the advised action to reduce the risk or seriousness of an impact)	12	Correct and reasonable prenatal physical activity are feasible.	0.92
	13	I can prevent pregnancy complications, such as obesity, gestational diabetes and gestational hypertension, preeclampsia, and urinary incontinence, if I get enough prenatal physical activity.	
	14	I can regulate anxiety and depression if I get enough prenatal physical activity.	

Table 1. *Cont.*

Dimensions	Item Number	Items	Cronbach's α
	15	I can promote the health of the fetus if I get enough prenatal physical activity.	
	16	I can reduce adverse pregnancy outcomes if I get enough prenatal physical activity.	
Perceived barriers (Belief about the tangible and psychological costs of the advised action)	17	It is difficult for me to participate in physical activity without being in good physical condition.	0.85
	18	I am lazy and have no interest in pregnancy exercise.	
	19	It is hard for me to get involved in pregnancy exercise if I do not have enough money and belong to a professional maternity organization.	
	20	It is hard for me to get involved in prenatal physical activity without other people supporting me.	
Cues to action (Strategies to activate readiness and promote awareness)	21	Prenatal physical activity information on TV commercials and publication propaganda impact me.	0.80
	22	Prenatal physical activity experiences from family members and friends impact me.	
	23	Views of doctors and coaches on prenatal physical activity impact me.	
Self-efficacy (Confidence in one's ability to take action)	24	I am willing to participate in prenatal physical activity.	0.81
	25	I can complete the assigned task while participating in prenatal physical activity.	
	26	I can make up my mind to correct my bad habits while participating in prenatal physical activity.	
	27	I can exercise independently during pregnancy.	
	Overall		0.91

2.2.2. Pregnancy Physical Activity-Related Health Belief Model Assessment

The reliability score of the entire HBM scale, represented by Cronbach's alpha, was 0.91. Confirmatory factor analysis (CFA) was performed to identify the construct validity, convergent validity, and discriminant validity between factors and measurement items [24]. The standard estimate of 27 items was greater than 0.6, indicating an effective measurement relationship (Figure 1). The average variance extraction (AVE) values of the seven factors were all greater than 0.5, and the combination reliability (CR) values were all greater than 0.7, signifying that the data in this analysis had sound construct validity. The AVE square-root values of the seven factors were all greater than the absolute value of the correlation coefficient between the factors, meaning that the factors had high discriminant validity. A construct validity test of CFA was performed, and the following fit statistics were obtained: root mean square error of approximation = 0.08 (<0.1 indicates good fit), goodness of fit index = 0.91 (>0.90 indicates good fit), Chi-square value/degree of freedom ($\chi 2/df$) = 2.9 (<3 indicates good fit), and comparative fit index = 0.92 (>0.90 indicates good fit). Figure 1 presents the factor structure of the HBM and the standardized path coefficient.

2.2.3. Data Collection

Data were collected using professional online questionnaire survey technology (WenJuanXin), and a link or quick-response (QR) code for the electronic questionnaire was created to make it easier for participants to scan the code and complete it on their smartphone. Data were gathered from May to August 2021. Senior midwives observed the data collection process for quality control with the express permission of participants who fulfilled the inclusion criteria. Participants were instructed on how to complete the questionnaire and were informed of issues to be addressed. Logic-based questions and limitations were added to the questionnaire survey software to ensure respondents did not miss questions and repeat engagements. Once the questionnaire was completed, the same phone could not scan the QR code. However, if the anomalous data varied considerably from the typical value, it was removed, or if the respondent's unit of height, weight, or age was not in accordance with the requirements, it could be manually changed. According to the CFA suggestion and calculation result of sample size (α = 0.05, d = 0.3, and 1−β = 0.8) [24], 300 questionnaires were estimated to be collected. A total of 425 electronic questionnaires were collected, with 11 marked anomalous data. There were 414 valid electronic questionnaires after deleting 11 samples that departed from the normal value.

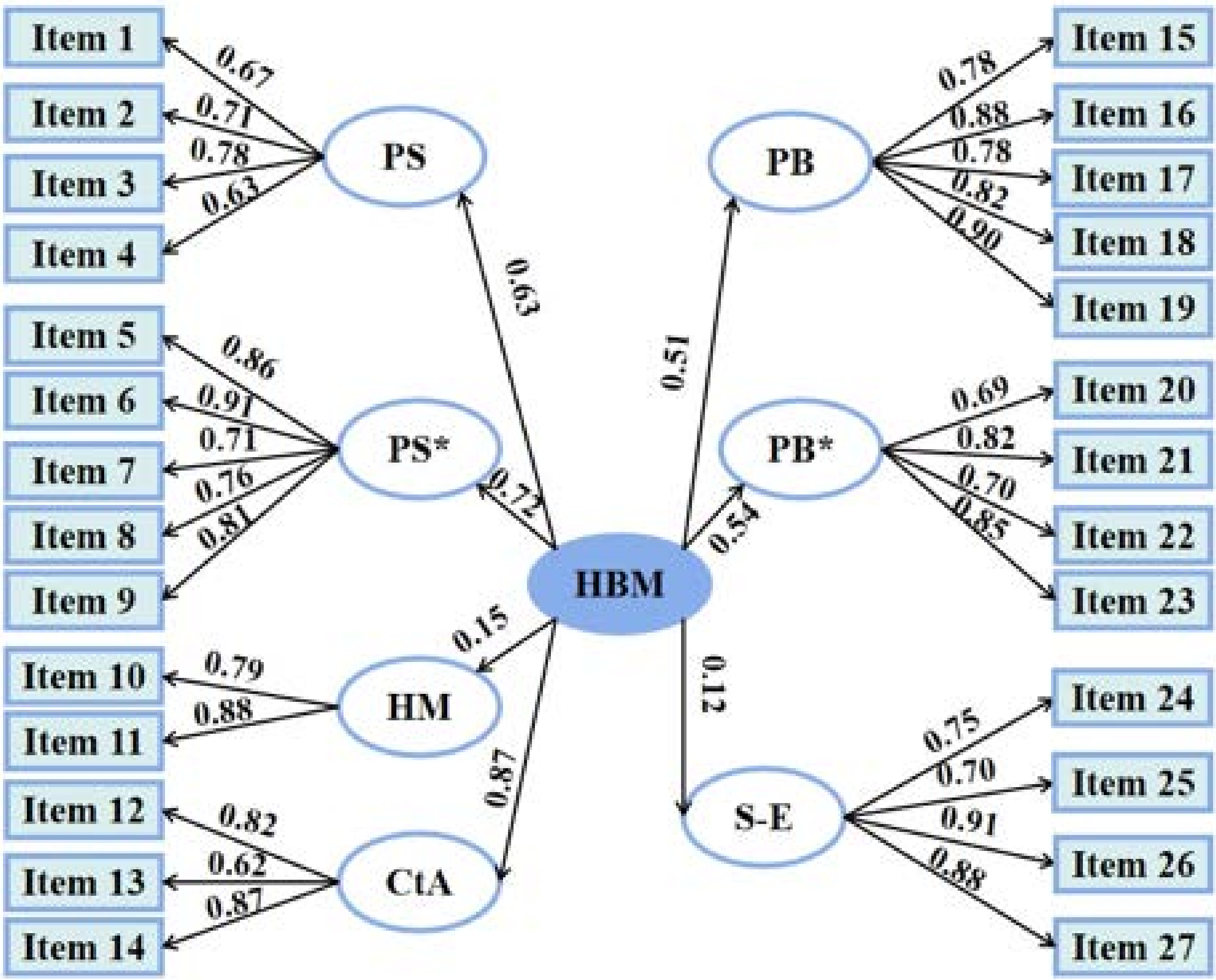

Figure 1. Health belief model (HBM) path diagram and the standardized path coefficient. PS: perceived susceptibility; PS*: perceived severity; HM: health motivation; PB: perceived benefits; PB*: perceived barriers; S-E: self-efficacy; CtA: cues to action; HBM: health belief model.

2.3. Statistical Methods

G*power (version 3.1.9.4) was used to compute the required sample size. Statistical Product and Service Solutions (SPSS) version 26.0 was used to analyze the validity and reliability of the health belief questionnaire. OriginPro 2021 (version 9.8.0.200, OriginLab Corporation) was utilized to conduct the analysis of variance (ANOVA) and the Pearson correlation coefficient assessment. ANOVA was chosen to evaluate variations in each group's health beliefs and PPA levels. CFA was used to identify the construct validity, convergent validity, and discriminant validity of the factors. The Pearson correlation coefficient was performed to analyze the link between participants' demographic features, their PPA-related HBL, and PPA. The R programming language (version R x64 4.1.1, R Development Core Team) was used to build the classification and regression tree (CART) [25] to elucidate the precise effect of each moderator variable on PA behavior in pregnant women. The binary tree serves as a logical framework for constructing prediction criteria on the basis of current research data. PPA-related factors served as the study's input variables, with PPA energy expenditure values serving as its outcome variables.

3. Results

3.1. Demographic Characteristics

The demographic characteristics of the 414 respondents are presented in Table 2. Participants were Chinese citizens (100%); 202 (48.9%) aged 26 to 34; 259 (62.5%) were of Han nationality; 141 (34.1%) were living in urban areas; pregnant nulliparous women (42.6%) and pregnant parous women (57.4%), of whom 34.2% were in the third trimester. A total of 41.1% of the participants in this study had children. Participants with bachelor's degrees composed more than half of the study population (50.3%), and most of their spouses also had bachelor's degrees (46.6%). Approximately 26% of the population had an annual income below CNY 50,000 (Table 2).

Table 2. Demographic features of the study participants (*n* = 414).

Variable	N (%)
Chinese citizen	414 (100%)
Age (years)	
20–25	161 (38.9%)
26–34	202 (48.9%)
35+	51 (12.2%)
Body mass index	
Underweight	41 (9.8%)
Normal weight	289 (69.9%)
Overweight	59 (14.2%)
Obese	25 (6.1%)
Nationality	
Han	259 (62.5%)
Minority	155 (37.5%)
Annual revenue per capita	
Less than CNY 50,000 per year	108 (26%)
CNY 50,001–100,000 per year	104 (25%)
CNY 100,001–150,000 per year	48 (11.5%)
More than CNY 150,000 per year	128 (31.1%)
Unsure/would rather not say	26 (6.4%)
Highest educational level	
No schooling or primary school	4 (1%)
Secondary/high school	59 (14.2%)
Technical or further educational institution	84 (20.3%)
Bachelor's degree	208 (50.3%)
Master's degree	59 (14.2%)
Highest educational level (spouse)	
No schooling or primary school	8 (2%)
Secondary/high school	78 (18.9%)
Technical or further educational institution	76 (18.3%)
Bachelor's degree	193 (46.6%)
Master's degree	59 (14.2%)
What is your current number of children?	
None	244 (58.9%)
1 child	122 (29.5%)
2 children	45 (10.9%)
3 or more children	3 (0.7%)
Pregnancy for the first time	
Yes	126 (42.6%)
No	170 (57.4%)

Table 2. *Cont.*

Variable	N (%)
Trimester of gestation	
First trimester	99 (33.4%)
Second trimester	96 (32.4%)
Third trimester	101 (34.2%)
Residential zone	
Urban	141 (34.1%)
Suburban	133 (32.1%)
Rural	140 (33.8%)

3.2. Health Belief Level (HBL) and Prenatal Physical Activity

Figure 2 displays the results and compares each HBM dimension and HBL among nonpregnant nulliparous, pregnant nulliparous, and parous women, as indicated by each dimension's weighted HBL scores and mean scores. All dimensions of individual perceptions were examined, and a statistically significant difference was observed in the reported perceived susceptibility, severity, and benefits between nonpregnant nulliparous and pregnant parous women ($p < 0.05$). Nonpregnant nulliparous and pregnant nulliparous participants differed significantly in perceived barriers and HBL ($p < 0.05$), whereas health motivation, cues to action, and self-efficacy were not significantly different ($p > 0.05$). The pregnant parous group had the highest HBL (3.42 ± 0.58), followed by the pregnant nulliparous (3.24 ± 0.57) and nonpregnant nulliparous women (3.06 ± 0.58). The highest score was achieved for health motivation (3.95 ± 0.72) in pregnant nulliparous women, whereas the lowest score was achieved for perceived susceptibility (2.97 ± 0.78) in nonpregnant nulliparous women.

3.3. Physical Activity Expenditure during Pregnancy

Pregnant parous women had the highest energy expenditure for housekeeping (1.83 MET-h/week) and the lowest for exercise (1.10 MET-h/week), and their total energy expenditure was 6.01 MET-h/week. The pregnant nulliparous group had the highest energy expenditure for work (1.80 MET-h/week) and the lowest for exercise (0.76 MET-h/week), and their total energy expenditure was lower than that of the pregnant parous group (5.67 MET-h/week). However, pregnant nulliparous and pregnant parous women exhibited no statistically significant difference in energy expenditure for housework, transportation (driving to and from work), and work ($p > 0.05$). A significant difference in energy expenditure for exercise was observed between pregnant nulliparous and pregnant parous women ($p < 0.05$) (Figure 3).

3.4. The Association between Demographic Factors, Health Belief Model Dimensions, and Pregnancy Physical Activity

In this study, all variables were selected and classified based on the HBM categorization, and they were divided into demographic characteristics (Table 2) and HBM dimensions (Table 1). A Pearson correlation coefficient analysis was performed to assess the correlations between demographic characteristics, HBM dimensions, and PPA. All HBM dimensions were positively correlated with exercise expenditure in both the pregnant nulliparous and pregnant parous groups, except for perceived barriers. By contrast, perceived barriers, age, body mass index (BMI), and trimester of pregnancy were negatively correlated with housework and work activities in pregnant nulliparous women. Location was negatively correlated with work in both pregnant nulliparous and pregnant parous women (Figure 4).

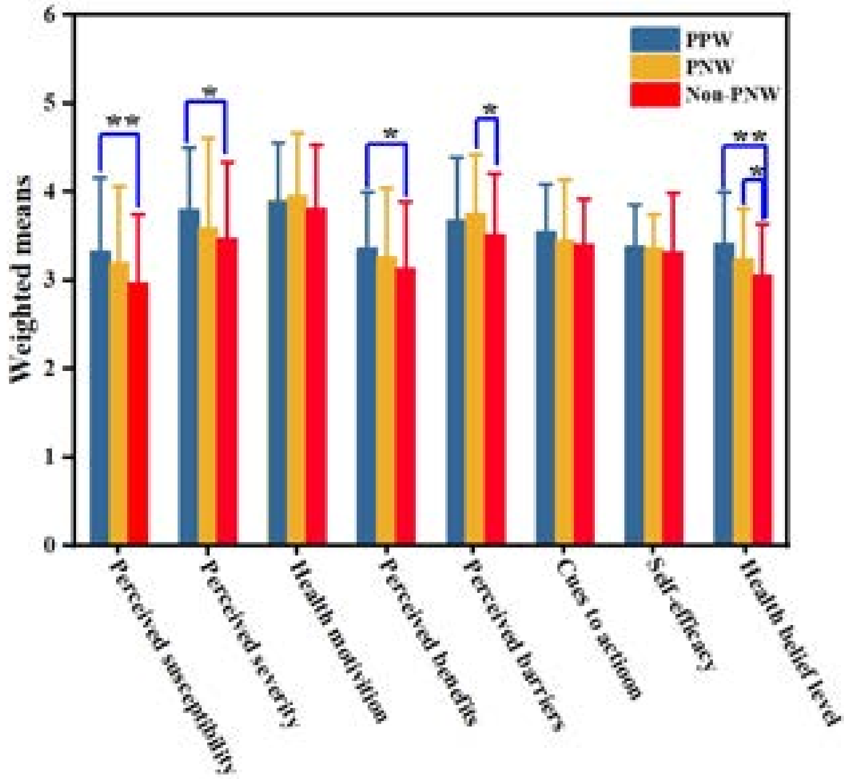

Figure 2. Comparison of health belief dimensions among nonpregnant, pregnant nulliparous, and pregnant parous women. Note: PPW: pregnant parous women; PNW: pregnant nulliparous women; Non-PNW: nonpregnant nulliparous women; ** $p < 0.01$; * $p < 0.05$.

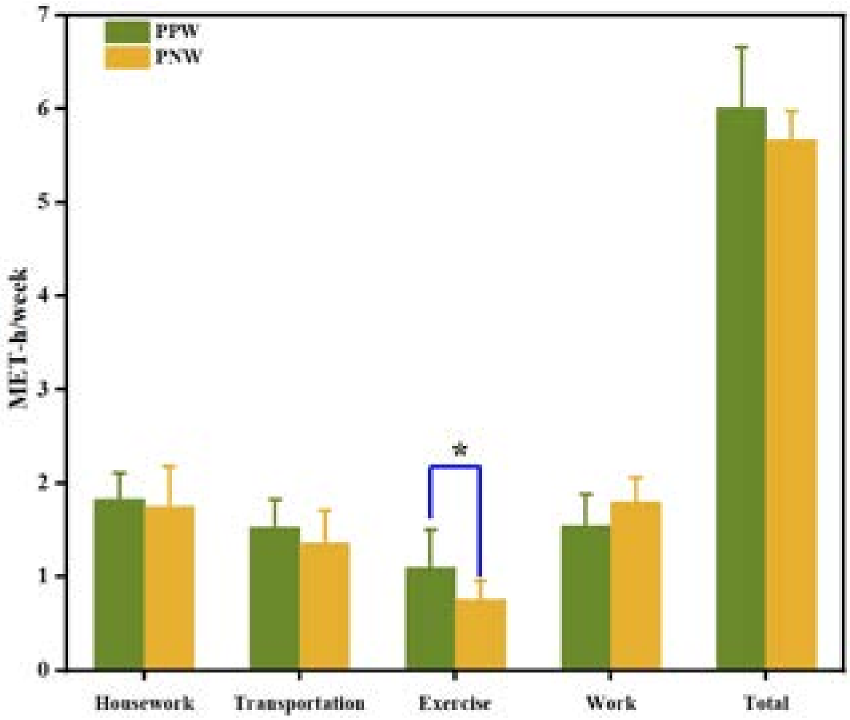

Figure 3. Mean difference in physical activity expenditure between pregnant nulliparous and pregnant parous women. Note: MET-h/week: metabolic equivalent-hours per week; PPW: pregnant parous women; PNW: pregnant nulliparous women; * $p < 0.05$.

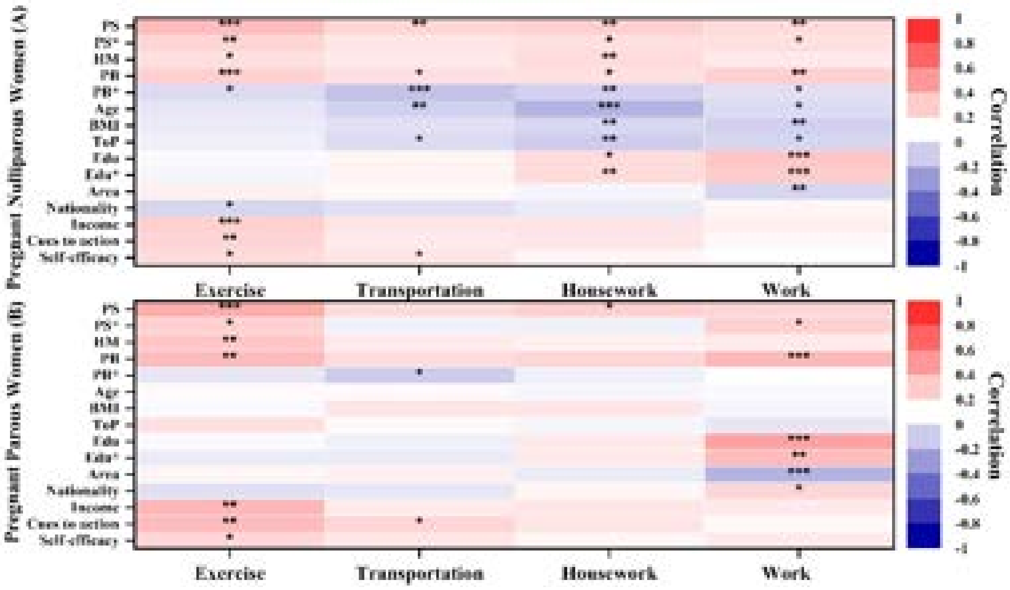

Figure 4. Heat maps of the Pearson correlation of demographic and health belief model (HBM) dimensions and prenatal physical activity. The pregnant nulliparous group is shown in the first map, and the pregnant parous group is shown in the second map. PS: perceived susceptibility; PS*: perceived severity; HM: health motivation; PB: perceived benefits; PB*: perceived barriers; BMI: body mass index; ToP: trimester of pregnancy; Edu: participant's education background; Edu*: spouse's education background; ***: significant correlation at $p < 0.001$; **: significant correlation at $p < 0.01$; *: significant correlation at $p < 0.05$. A darker color indicates a stronger association and vice versa; red is positively correlated, whereas blue is negatively correlated.

A Pearson correlation coefficient analysis was performed between demographic factors and HBM dimensions, taking into account the variables' interconnectedness. Figure 5 displays the correlation between demographic factors and HBM dimensions. In both pregnant nulliparous and pregnant parous women, income was positively linked to HBM dimensions (except for perceived barriers). In the pregnant nulliparous group, the spouse's education background was positively correlated with perceived susceptibility, benefits, and health motivation. However, in both pregnant nulliparous and pregnant parous women, the residential zone was negatively correlated with perceived benefits, and age and BMI were negatively correlated with health motivation but positively correlated with perceived barriers.

3.5. Construction of Classification and Regression Tree (CART)

The classification and regression tree (CART) [25] was used to predict the values of pregnant women's PA during COVID-19. In this research, various PPA-related factors served as the categorical factors, and energy expenditure served as the target variable. The splitting criterion was the mean square error, and feature selection was conducted to generate a binary tree. Each CART leaf corresponds to a predictive value equal to the mean energy expenditure. The internal node feature has two functions: "Yes" or "No." The left branch has the value of "Yes," and the right branch has the value of "No." We analyzed the two groups according to the pregnancy experience difference between the pregnant nulliparous and pregnant parous groups. The following are the CART outcomes: among women who were pregnant for the first time, participants aged ≤ 23 years with an annual household income of $\geq$CNY 100,001–150,000 had the highest predicted value (mean = 10.75 MET-h/week); participants aged > 23 years with a perceived severity score of >3.1 who were in the second trimester of gestation and had a perceived susceptibility score < 2.8 had the lowest predicted value (mean = 3.25 MET-h/week). In the group of women who had been pregnant more than once, those participating with perceived benefits score > 4 had the highest predicted value (mean = 10 MET-h/week);

participants aged ≥ 29 with a health motivation score > 4 had the lowest predicted value (mean = 3.4 MET-h/week). Figures 6 and 7 show the categorical factors structure on the predicted value of PPA in pregnant nulliparous and pregnant parous women.

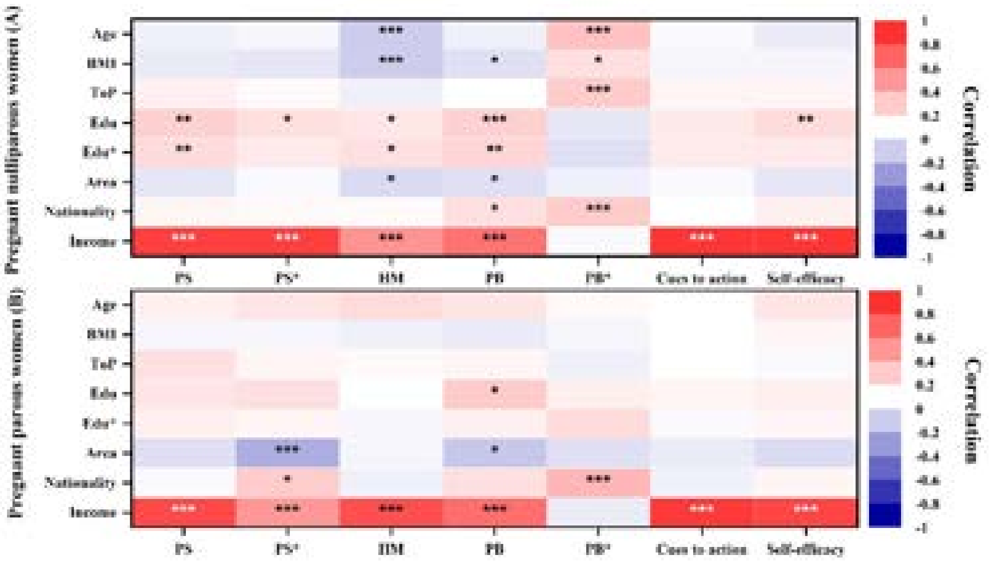

Figure 5. Heat maps of the Pearson correlation of demographic and health belief model (HBM) dimensions. The pregnant nulliparous group is presented in the first map. The pregnant parous group is shown in the second map. PS: perceived susceptibility; PS*: perceived severity; HM: health motivation; PB: perceived benefits; PB*: perceived barriers; Edu: participant's education background; Edu*: spouse's education background; BMI: body mass index; ToP: trimester of pregnancy. ***: significant correlation at $p < 0.001$; **: significant correlation at $p < 0.01$; *: significant correlation at $p < 0.05$. A darker color indicates a stronger correlation and vice versa; red is positively associated, whereas blue is negatively associated.

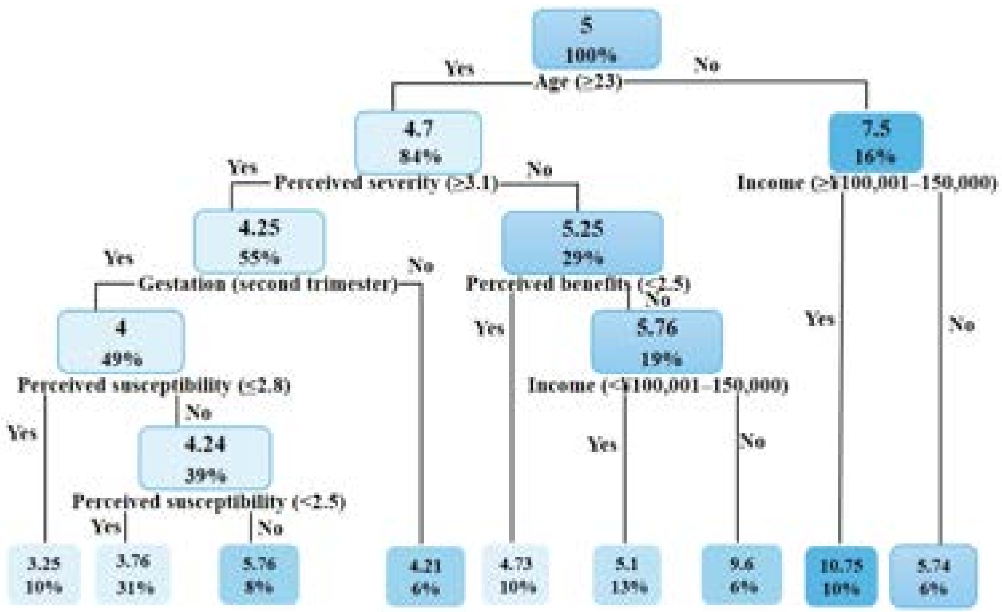

Figure 6. The classification and regression tree illustrated the predicted values of physical activity level in pregnant nulliparous women. Note: The values in the rectangle indicate the amount of energy expenditure (metabolic equivalent (MET)-hours per week) and the percentage of the samples taken.

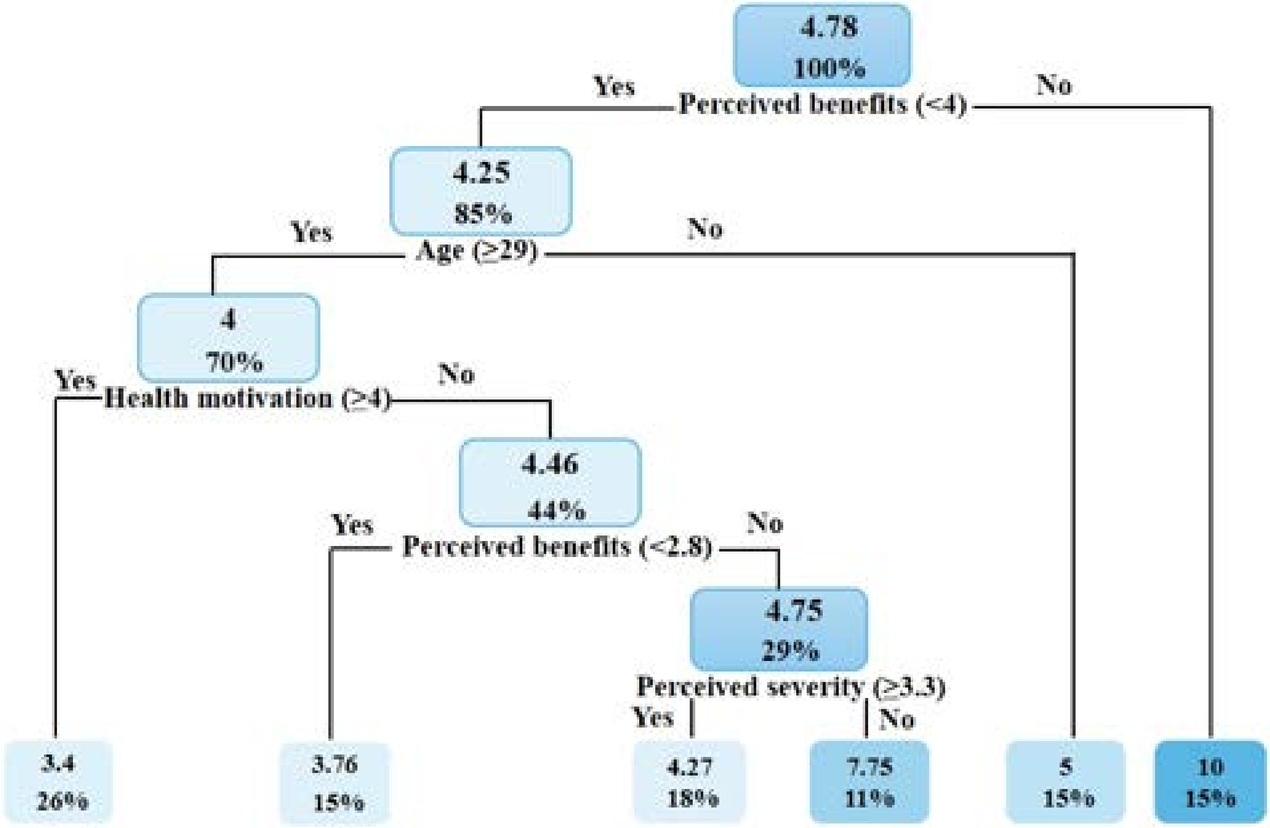

Figure 7. The classification and regression tree illustrated the predicted values of physical activity level in pregnant parous women. Note: The values in the rectangle indicate the amount of energy expenditure (in MET-h/week) and the percentage of the samples taken.

4. Discussion

The current research used the HBM to investigate the HBL in nonpregnant and pregnant women, offering novel insight into the relationship between psychosocial and physiological factors and PPA behaviors in 414 Chinese women of reproductive age. The findings reveal most respondents were insufficiently physically active throughout their pregnancy during COVID-19, preventing them from enjoying the benefits of PA, and the HBL in all groups was acceptable. Furthermore, the HBL in the nonpregnant nulliparous group was significantly lower than in pregnant nulliparous and pregnant parous women. HBL was most strongly correlated with exercise energy expenditure in both pregnant nulliparous and pregnant parous women. Overall, the primary hypothesis was validated: the HBL of nonpregnant nulliparous women was lower than that of pregnant nulliparous and pregnant parous women, and PPA was lower than the recommended PA level during COVID-19. Health attitudes and demographic variables were correlated with PPA, which was consistent with the hypothesis.

4.1. Overview of Hypothesis Validation Findings

4.1.1. Health-Belief Level (HBL)

This research indicated that the HBL was acceptable among nonpregnant nulliparous and pregnant nulliparous, and pregnant parous women, with perceived severity (only in the pregnant parous group) and health motivation above the median level, whereas perceived susceptibility was poor in the nonpregnant nulliparous group. This indicates that the participants had a favorable attitude toward PPA and exercise during pregnancy, and they believed that they would participate in PPA [26]. However, women lack awareness about PPA; therefore, few women are aware of the dangers of inactivity and the benefits of activity while pregnant [27]. Moreover, nonpregnant nulliparous women had a significantly lower HBL and significantly lower perceived susceptibility, severity, benefits, and barriers scores than pregnant women, which aligns with our hypothesis. They had lower awareness of the hazards associated with inactivity, which may lead to prenatal physical inactivity, harming their health and that of their unborn children or causing illness when they become pregnant [6]. Janakiraman et al. [28] discovered that women who were educated about the advantages and hazards of PA, the dangers of inactivity, and various exercise methods exhibited more favorable attitudes toward PPA. Accordingly, early and systematic education on the benefits and knowledge of PPA based on the current HBL is required for Chinese women, especially young women who have not given birth. In addition, scores for perceived barriers matched the median scores in nonpregnant nulliparous, pregnant nulliparous, and pregnant parous women, suggesting that pregnant women in China may experience or have previously faced barriers to PPA. According to the item score for perceived barriers, the main barriers were laziness, lack of interest, and inconvenience. Perhaps one of the main explanations for this occurrence is that with the growth of the global electronic product industry, the focus is shifting away from sports and toward smartphones, computers, and other electronic devices [29]. Another explanation may be that during the COVID-19 pandemic, individuals were typically required to remain at home which consequently decreased their PA [30].

4.1.2. Physical Activity Status of Pregnant Women

In this study, pregnant women showed the greatest energy expenditure in housekeeping and the lowest in exercise during pregnancy. This indicated that most pregnant women in China did not perform moderate-intensity exercise (e.g., swimming, running, and climbing) during pregnancy. Their total energy expenditure during the COVID-19 pandemic was less than 7.5 MET-h/week recommended by ACOG. Our observations are consistent with the findings of Hori et al. [31] and Ghesquière et al. [32], who reported that pregnant women are usually inactive. After pregnancy, women's PA progressively declines, a typical occurrence among pregnant women in China and overseas, and this has been particularly apparent during the COVID-19 pandemic [31]. Traditional Chinese society views pregnancy as a delicate time when women should rest and be protected [33]. To prevent miscarriage and minimize pressure from family and friends, Chinese pregnant women prefer to follow traditional advice, such as "Do not leap," "Do not lift heavy items," "Do not walk too quickly," and "Do not walk too much [34]." The above information may partially explain why pregnant Chinese women tend to be inactive and prefer to stroll instead of engaging in more strenuous activities. Meanwhile, social isolation is essential to prevent the spread of the novel coronavirus [35]. Many types of social engagement, including sports, have been halted; people remain pessimistic about these activities because of the current scenario. Pregnant women with weak immune systems are advised to avoid public places as much as possible to minimize the risk of infection [3]. However, the current COVID-19 pandemic necessitates that these individuals engage in enough exercise to boost their resistance to the virus [36], presenting additional obstacles for pregnant women.

4.1.3. Connection between Health Belief, Demographic Factors, and Prenatal Physical Activity

The correlation analysis demonstrated that HBL, demographic factors, and PPA were linked. Consequently, the HBM may serve as a reliable foundation for investigating variables that influence PPA during pregnancy and further clarifying the relationships between various factors. The HBM dimensions were positively correlated with exercise in pregnant nulliparous and pregnant parous women, which is consistent with the findings of Li Jingfang et al. [37]. This may be because individual perception is inextricably linked to behavior, which underlies the theoretical foundation for knowledge, attitude, belief, and practice (KABP) model and HBM [38]. Meanwhile, HBM and KABP model-based behavioral interventions have been shown to effectively promote smoking cessation, mental illness treatment, and breastfeeding [39]. Accurate and comprehensive perception creates the foundation for individuals to engage in beneficial behavior [38]. People may make erroneous decisions because they have formed false perceptions about a situation [38]. However, perceived barriers, age, BMI, and trimester of pregnancy were negatively correlated with PPA in the pregnant nulliparous group. Fewer physiological variables were linked to PPA in the pregnant parous group. Moreover, higher levels of knowledge and cognition were found in the pregnant parous group, who may encounter fewer obstacles and physical issues [40]. Hence, different groups may perceive the effects of PA differently, depending on their physiological factors and knowledge. Education, income, ethnic group, and geographic location were correlated with exercise- and work-related energy expenditure in pregnant nulliparous and pregnant parous women. Women from higher-income backgrounds who were more educated or who lived in metropolitan areas were more likely to overcome obstacles to engage in regular PPA [41]. Regarding the influence of ethics on PPA, differences were observed between the Han nationality and the minority group, which may be attributed to differences in culture and habits [42].

We also conducted a correlation analysis between demographic factors and HBM dimensions. In the pregnant parous group, there were no physiological variables linked to HBM dimensions. However, age, BMI, and trimester of pregnancy were linked to perceived barriers and health motivation in the pregnant nulliparous group, suggesting that older women had higher BMI, later stage of pregnancy, and more PPA-related obstacles but low health motivation. Pregnant nulliparous women are more likely to avoid PPA because of their weight and stage of pregnancy. They may feel fatigued and be concerned about the possibility of miscarriage [43]. Education, income, and geographic location were linked to HBM dimensions in pregnant nulliparous and pregnant parous women. Women from higher-income backgrounds who had more education or lived in metropolitan areas were more likely to have high HBL. Educational background influences a person's degree of health perception, and income directly influences their living standard [44]. An individual with a decent income and extensive health knowledge is likely to have greater health cognition and purchase superior health products [44,45].

4.2. Classification and Regression Tree

A regression tree is a prediction model that depicts a mapped connection between object attributes and object values. It is a graphical technique that applies probability analysis intuitively and has minimal prediction error [25]. After determining the previously recorded energy expenditure of PA during pregnancy, the object attribute values (demographic and HBM dimensions) were input to build a regression tree, which produced the projected value of the PPA, possibly enabling the creation of intervention strategies. According to the regression-tree results, young women with a high income (annual household income of >CNY 100,001–150,000) and older women with higher perceived susceptibility, severity, and benefits are more likely to participate in PPA during nulliparous pregnancy. The results for the pregnant parous group revealed that perceived benefits had a direct effect on the PPA value and that PPA can be achieved at the recommended level among older pregnant women with greater health motivation, perceived benefits, and severity. This indicates that the impact of perceived benefits was more prominent among pregnant parous women, and they may overcome barriers to participating in PPA if they perceive the advantages, have sufficient health motivation, and are aware of the dangers of inactivity. Additionally, this example demonstrates the value of experience, which may help pregnant women comprehend the advantages of PPA.

The study findings revealed the following major points: (1) more than half (51%) of the participants had an annual income of less than CNY 100,001; (2) the perceived susceptibility, severity, and benefits levels in this survey were not high; (3) pregnant nulliparous women in their second and third trimesters, as well as older pregnant women, were hesitant to engage in PPA; (4) the PPA level was lower than the recommended level during the COVID-19 pandemic; and (5) the item score for media coverage, income, and professional coaching advice in cues to action was high. Additionally, professional prenatal exercise facilities (e.g., pregnancy exercise classes offered by medical institutions and specialized commercial pregnancy exercise clubs) in China are primarily located in developed regions [46]. Consequently, they are costly, and low-income families and those living in underdeveloped areas cannot afford to pay the exorbitant fees [46]. Furthermore, PPA guidelines from a multidisciplinary team of specialists may be hindered by a lack of professional coaches, financial support, and infrastructure during the COVID-19 era. To address the lack of professional institutions, unreasonable prices, safety concerns, etc., female-centered organizations should hold monthly public interest courses for pregnant women at different stages of pregnancy to alleviate the financial strain placed on young people by their families and enhance awareness of the dangers surrounding inactivity and the benefits of activity while pregnant. For instance, women's associations and communities could increase publicity, universities could invite expert physicians and coaches to offer relevant courses, and a network platform could be established to minimize equipment expenses and ensure safety in the context of COVID-19. For instance, mobile applications (e.g., apps focused on weight management, mental health, nutrition knowledge, counseling medical personnel, and exercise training online) may be beneficial for improving maternal physical and mental health during the pandemic, and affordability represents a major advantage of mobile apps [47,48]. The government may consider providing special activity venues and facilities for pregnant women when planning various community construction projects. Inactivity during pregnancy may be alleviated by providing women with tailored pregnancy education. In addition, evidence-based recommendations on modern prenatal exercise programs should be developed and promoted among pregnant women, exercise and health professionals, and obstetric care providers [49].

4.3. Strengths and Limitations

Several advantages and disadvantages of the current research should be taken into account when evaluating the results. First, the sample consisted of nonpregnant and pregnant women who were available and willing to participate from China's central and western regions. Thus, the results may not be generalizable to pregnant women residing in other parts of China, such as large metropolitan regions, or to ethnic minorities. Second, only self-reported measurements were used to assess PPA levels due to the prohibitive cost and practical difficulty of objectively assessing the PPA levels (e.g., using accelerometers) in such a large group of respondents. Third, this research only gathered cross-sectional data, making it impossible to draw conclusions on longitudinal changes in individual activity levels. Furthermore, prepregnancy PA was not collected from the pregnant participants because of recall bias [50]; consequently, the PA of nonpregnant nulliparous women was not investigated. Longitudinal studies that investigate PA before and during pregnancy in a population-based sample are suggested in the future. Unlike other Chinese studies [37,51,52], this research examined PPA levels in nulliparous and parous pregnancies during the ongoing COVID-19 pandemic. Additionally, HBL was investigated in women of different socioeconomic levels, placing emphasis on reproductive-age women who had not given birth. The correlation between physiological factors and HBL and PPA was verified. The pregnancy HBM can be a vital tool for motivating pregnant women to engage in PA throughout their pregnancy. Prior research has demonstrated that pregnant women generally have a reduced level of PA. However, this study offers much-needed information on changes in the moderators, individual perceptions, and the energy expenditure of PPA performed by pregnant women. We then used a regression tree to estimate the energy expenditure of PA, which may enable the creation of intervention strategies, given that these variables may have varied effects depending on geography, economy, and culture. It is essential to identify the elements that influence women's exercise programs during pregnancy in various regions and to understand how exercise behavior is connected to individual perception and moderator variables to guide future local policies and practices.

5. Conclusions

In this study, demographic characteristics, HBL, and PPA were investigated in Chinese women who were nonpregnant nulliparous, pregnant nulliparous, and pregnant parous. All HBM dimensions had a positive relationship with exercise energy expenditure in both pregnant nulliparous women and pregnant parous women, except for perceived barriers. According to the regression tree, the predicted PPA value would meet the recommended level in young pregnant nulliparous women with high incomes; perceived benefits directly affected the PPA value in the pregnant parous group. These findings may prove useful in establishing population subgroups that require intervention, and they may provide evidence for future recommendations regarding PA during pregnancy.

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A Comparison of Functional Features of Chinese and US Mobile Apps for Pregnancy and Postnatal Care: A Systematic App Store Search and Content Analysis

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Background: Pregnancy to postpartum (PtP) applications (apps) are becoming more common tools to document everything from pregnancy and delivery to nutrient allocation, life taboos, and infant medical examinations. However, the dependability, quality, and efficacy of these apps remain unclear. This study examined the features and functions of mobile PtP care apps accessible in China and the United States and to identify the major gaps that need to be addressed.

Methods: Apps were selected by searching the Apple App Store and Android Markets (in the US and China) for the terms "pregnancy" and "postpartum" in Chinese and English. The apps' security, quality, and effectiveness were investigated, and chi-square tests and analysis of variance were performed to examine the differences in characteristics between apps available in the US and China.

Results: A total of 84 mobile PtP care apps (45 from the US and 39 from China) were included. A total of 89.7% (35/39) of Chinese mobile apps did not provide safety statements or supporting evidence. The objective app quality ratings for Chinese and US apps were 3.20 ± 0.48 (mean ± standard deviation) and 3.56 ± 0.45, respectively ($p > 0.05$). A greater number of Chinese apps provided app-based monitoring functions, namely recording fetal size ($n = 18$, 46.2% in China vs. $n = 3$, 6.7% in the US), contractions ($n = 11$, 28.2% in China vs. $n = 0$, 0% in the US), pregnancy weight ($n = 11$, 28.2% in China vs. 0, 0% in the US), and pregnancy check-up reminders ($n = 10$, 25.6% in China vs. $n = 0$, 0% in the US). Meanwhile, a greater number of US apps provided exercise modules, namely pregnancy yoga ($n = 2$, 5.1% in China vs. $n = 21$, 46.7% in the US), pregnancy workouts (n = 2, 5.1% in China vs. n = 13, 28.9% in the US), and pregnancy meditation ($n = 0$, 0% in China vs. 10, 22.2% in the US) ($p < 0.01$). A medium security risk was identified for 40% (18/45) of apps in the US and 82.1% (32/39) of apps in China ($p < 0.01$).

Conclusions: The functionality and characteristics of in-store mobile apps for PtP care varied between China and the US. Both countries' apps, particularly Chinese apps, encountered issues related to a lack of evidence-based information, acceptable

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content risk, and program evaluations. Both countries' apps lacked proper mental health care functions. The findings suggest that the design of app features should be enhanced in both countries, and increased interaction between app creators and users is recommended.

Keywords: pregnancy, postnatal care, mobile app, China, functionalities, United State of America

INTRODUCTION

The pregnancy to postpartum (PtP) stages are critical because, during this period, a woman's health is very vulnerable (1, 2). The 22nd Annual Meeting of the International Federation of Obstetrics and Gynecology discussed the present condition of PtP health care throughout the world. Experts noted that health care during the PtP period is imperative and encompasses a range of health care measures for the mother and fetus before, during, and after pregnancy, as well as during the puerperium (lactation) and neonatal phases (3).

During the PtP period, everything from pregnancy and delivery to nutrient allocation (4), life taboos (5), and newborn physical examinations (6) must be closely monitored. Pregnancy and postnatal education and support provided by a multidisciplinary team of specialists (e.g., doctors, midwives, trainers, and psychotherapists) may enhance the quality of care (7, 8). However, they may be too expensive or unavailable in impoverished countries (9, 10). Additionally, coronavirus disease 2019 (COVID-19) and its corresponding isolation periods may harm the health of pregnant and postpartum women (11). Thus, a lack of professional coaches, financial support, and infrastructure may hinder the provision of PtP care from a multidisciplinary team of specialists.

Technological advancements have facilitated the rapid rise of electronic health (eHealth) and mobile health (mHealth) in recent years (12, 13). According to a recent survey in Switzerland, PtP applications (apps) are becoming increasingly popular (14): 91% of parents use digital media to learn about their child's health and development (15). Evidence from randomized trials and comprehensive reviews indicates that mobile apps are typically beneficial for improving maternal physical health (e.g., weight management, mental health, and pregnancy awareness) (16–18), and affordability is a major advantage of such apps (19). However, the programs available in app stores are highly varied in terms of function, design, and overall quality, and they are not always subjected to rigorous evaluation through effective randomized controlled trials (RCTs) (18, 19). Meanwhile, systematic reviews of RCTs on maternal apps described the information for software and hardware, intervention content and delivery, and limitations. They still highlighted the risks of RTCs, such as unclear allocation concealment, no evaluation of objective quality in intervention apps, and no published protocols (20–22). Furthermore, studies reviewing apps that cover children's first 1,000 days of life (from conception to the age of 24 months) have exclusively focused on the prenatal or postnatal phases, ignoring the continuity between the two periods and their combined effect on the health of the mother and child (23, 24). For instance, taking notes of medical treatment received by both mother and infant, communicating with health professionals, as well as monitoring the mother's sleep and mental health are all uncommon features in apps (25). The dependability, quality, and efficacy of currently available PtP care apps are unclear, which may be a barrier to health promotion because pregnant and postpartum women are more susceptible to external influences (e.g., media coverage, apps information, social variables) (26). Incorrect information on health care and lifestyle may lead to unnecessary worry or stress during the perinatal period (26, 27).

Unsurprisingly, however, data supporting the effectiveness of mobile apps (26) are lacking because of the wide range of properties, responsibility for information correctness, degree of trustworthiness, and accessibility of content updates, as well as the absence of a certification mechanism or their categorization as a medical device (28). Furthermore, conventional app design and assessment procedures ignore the health literacy level of the target demographic and are disconnected from users' actual requirements (29, 30). Users' decisions may be influenced by variables such as an app's popularity, aesthetics, functionality, and user engagement (29, 30). However, one study revealed that many users did not critically evaluate the authenticity of the content offered by apps or consider problems related to their personal information and data (31).

Based on a review of recent studies of the impact of mHealth on the PtP period, two results emerged: (1) the importance of mothers receiving accurate health information throughout their children's first 1,000 days of life (2, 17) the major influence of mHealth on maternal well-being, lifestyle, and decision-making about pregnancy and infant health (32). Given these considerations, as well as the substantial gaps in the current research, several factors are unknown: (1) the authenticity, quality, and effectiveness of the most recent upgraded content provided by PtP care apps; (2) whether the apps consider privacy and security issues when collecting personal information and data. Therefore, a comprehensive study of current PtP care apps is timely and necessary during the COVID-19 pandemic.

Thus, the purposes of this study were to (1) describe and analyze the features and functions of mobile apps for PtP care available in China and the US, two of the largest app markets; (2) examine the apps' security, quality, and effectiveness; and (3) provide suggestions for future development and usage of mobile apps for PtP care of mothers and children throughout the first 1,000 days of life. On the basis of these goals, we anticipated that (1) the functions and features of PtP care apps in the US and China would be similar; (2) the latest upgraded content provided by apps would be high-quality and effective; and (3) all the apps would be concerned with the privacy and security of users' personal information and data.

MATERIALS AND METHODS

Data Source

An electronic search of apps was performed from June 11 to August 5, 2021, using the keywords "pregnant woman, 9/9 months of pregnancy," "birth," "infant," "baby," "obstetrics," "pregnancy," "postpartum," "new baby," and "kid" in both English and Chinese languages. We selected English- or Chinese-language apps from the Apple App store (in China and the US), Google Android Play (in the US), Huawei Android Market (Huawei Holdings Limited, in China), Baidu Android Market (Baidu, Inc., in China), and 360 Android Market (Qihoo 360 Technology Co., Ltd, in China).

App Selection Criteria and Data Extraction

The mobile apps for PtP care included in this study were defined as those that fulfilled any PtP health care needs. This study only included mobile apps with a minimum of 1 million downloads in the initial search list. Users are less likely to choose and download mobile apps with download numbers below this figure because they tend to choose the top mobile apps, which are ranked according to user comments and download count (28). The exclusion criteria were (1) duplicate and irrelevant apps (apps with the same name and producer were defined as duplicates, regardless of the availability of different versions); (2) apps without any meaningful introduction or instruction in the app store; (3) apps without a Chinese or English interface; (3) apps without a rating; (4) apps with fewer than 1 million downloads; (5) paid apps without trial; and (6) apps with no updates since January 1, 2020.

Two investigators independently chose the apps for inclusion in the study based on the inclusion criteria. The investigators extracted the following data from each included app: the app name, developer, specifications (medical, health, fitness, or unavailable), acquisition cost (free or in-app purchase), most recent update date, target users [women trying to conceive (TTC), pregnant women, postpartum women, those providing infant care, all types, or unspecified], safety statement (potential risks or "use under guidance" disclaimer), operating system (iOS or Android), supporting evidence (descriptive study, observational study, or randomized controlled trial), number of languages offered, user rating, and source of information (clinical guidelines). To avoid data omission, we compiled the aforementioned data into a spreadsheet, and each researcher used the same spreadsheet to document those data. Conflicts regarding inclusion and data extraction between the researchers were resolved through discussion.

In-depth Analysis of Perinatal Care Apps

To investigate the selected apps in depth, the apps were downloaded and installed on iOS and Android devices. Six independent researchers were each assigned the same number of apps. Two independent researchers registered and logged into each app to evaluate the quality of its content and functions; this ensured that each program was reviewed on both Apple App Store and the Android markets (Google, Huawei, Baidu, and 360). Where relevant, simulated input data, such as the predicted birth date and the start of the previous menstrual cycle, were utilized to accurately analyze the app's potential. For a comprehensive assessment of the functions of apps over the full pregnancy duration, two researchers pretended to be in the first trimester of pregnancy, two in the second trimester, and two in the third trimester. All investigators assessed and analyzed TTC and postpartum period information. The primary modules were recorded first, followed by the auxiliary functions inside each module after logging into the app. Each researcher utilized the same spreadsheet to document those data. Data on the apps' basic information of functionality and technological aspects were collected and analyzed between August 7 and October 20, 2021. The Fleiss Kappa value was used to measure the trustworthiness of the data gathered by the six researchers (33). The Mobile Application Rating Scale (MARS) was adopted to evaluate app quality through four dimensions of objective app quality, including engagement, functionality, aesthetics, and information quality (34). The subjective quality subscale of the MARS was omitted in the assessment since we aimed to assess the objective quality of apps. All MARS items were scored on a 5-point Likert scale ranging from 1 (inadequate) to 5 (excellent), with the researcher required to circle the number that most correctly indicated the quality of the app component under assessment (34). The mean scores for each dimension were calculated, and the mean total score of objective app quality was calculated across all 4 dimensions (34). Apps that scored $\geq$3 out of 5 on the MARS were considered acceptable quality, and scores higher than 4 were rated as high quality (35). Three independent MARS-trained reviewers scored ratings to the apps. Disparities and uncertainties regarding the scores of apps among the researchers were addressed through discussion and reached a consensus on the final MARS scores. The component, runtime, and communication security of all apps were examined by the national anti-fraud center (version 1.1.17), which was established by China's Ministry of Public Security in 2021 (36). Some of its fundamental capabilities are anti-fraud early warning, identification verification, app self-examination, and risk inquiry, which effectively check the security performance of App and reduce the possibility of individuals being swindled (36). Scores $<$60 out of 100 on the test report represented a high risk, scores $\geq$60 and $\leq$80 represented a medium risk, and scores $>$80 represented low risk (36).

Statistics Analyses

The baseline features were summarized using Origin (2021) (Northampton, MA, USA), and a chi-square test or analysis of variance with a significance threshold of 0.05 was performed using OpenEpi (version 3.01) to compare the Chinese and US apps (37). The module's frequencies and percentages were calculated using Origin (2021) (Northampton, MA, USA). Further, a chi-square test with a significance threshold of 0.05 was performed using OpenEpi (version 3.01) to analyze the functional differences between the Chinese and US apps.

RESULTS

Basic Characteristics of the Included Apps

Following a search of the Apple App Store, Google Play Store, Baidu Android Store, 360 Android Store, and Huawei Android Store, 817 apps were identified. After extensive screening, a total of 84 apps (39 from China and 45 from the US) were included. The flowchart in **Figure 1** illustrates the app selection process.

The characteristics of all the included apps are summarized in **Table 1**. Among the Chinese mobile apps, 10.3% (4/39) were classified as medical, 79.4% (31/39) were classified as health and fitness, and 10.3% (4/39) were unclassified. A total of 89.7% (35/39) of Chinese mobile apps lacked clear safety statements and supporting evidence, whereas among the US mobile apps, 53.3% (24/45) provided clear safety declarations, and 51.1% (23/45) supplied supporting evidence ($p < 0.01$). In terms of acquisition costs, the Chinese app markets offered more free apps than did the US ones [66.7% (26/39) in China vs. 13.3% (6/45) in the US; $p < 0.01$]. Furthermore, a higher percentage of Chinese apps were targeted at women TTC and infant-care users compared with US apps [women TTC: 46.2% (18/39) in China vs. 13.3% (6/45) in the US; infant-care: 41% (16/39) in China vs. 2.2% (1/45) in the US; $p < 0.05$]. In addition, Android systems were more common in China than in the US [79.5% (31/39) in China vs. 31.1% (14/45) in the US; $p < 0.01$]. Multiple languages were available in 43.5% (17/39) of Chinese apps, whereas multiple languages were only available for only 20% (9/45) of apps in the US ($p < 0.01$). In the US, none of the apps was uncategorized; 86.7% (39/45) of mobile apps were labeled as "health and fitness", whereas only 13.3% (6/45) were categorized as "medical". The number of in-app updates did not differ between the US and China apps after the COVID-19 outbreak; in 2021, 62.2% (28/45) of US apps and 74.4% (29/39) of Chinese apps were updated. US apps had an average user rating of 3.41; this was slightly higher than that of the Chinese apps, which had a mean user rating of 3.09 ($p > 0.05$).

Consistency of the Collected Content and Function Data of PtP Care Apps

Six independent researchers were assigned the same number of apps and were tasked with collecting the apps' information of functionality and technical characteristics. The Fleiss Kappa value was 0.8403, indicating that the authenticity and reliability of the apps' collected information of functions and technical characteristics were acceptable and could be analyzed.

Functions and Modules

The features of each function provided by the Chinese and US apps are represented in heat maps in **Figures 2**, **3**, and the data are summarized in **Table 2**. Chinese and US PtP care mobile apps contained seven functions [monitoring (e.g., recording fetal size, tracking physical activity during pregnancy, water intake, recording baby photos), nutrition, general education, exercise, community, purchasing, and others] and were targeted at four applicable groups (women TTC, pregnant women, postpartum women, and those providing infant care). Fewer app functionalities were comparable between the two countries. The most common function of the 39 Chinese apps was fetal size monitoring ($n = 18$, 46.2%), followed by general communication ($n = 16$, 41%), nutrition planning for pregnancy ($n = 15$, 38.5%), and nutrition knowledge throughout pregnancy (15, 38.5%). The most common function of the 45 US mobile apps was pregnancy yoga ($n = 21$, 46.7%), followed by monitoring physical activity in pregnancy ($n = 16$, 35.5%) and exercise during pregnancy ($n = 13$, 28.9%). Furthermore, none of the 39 Chinese mobile apps provided functions related to baby yoga, postpartum Pilates,

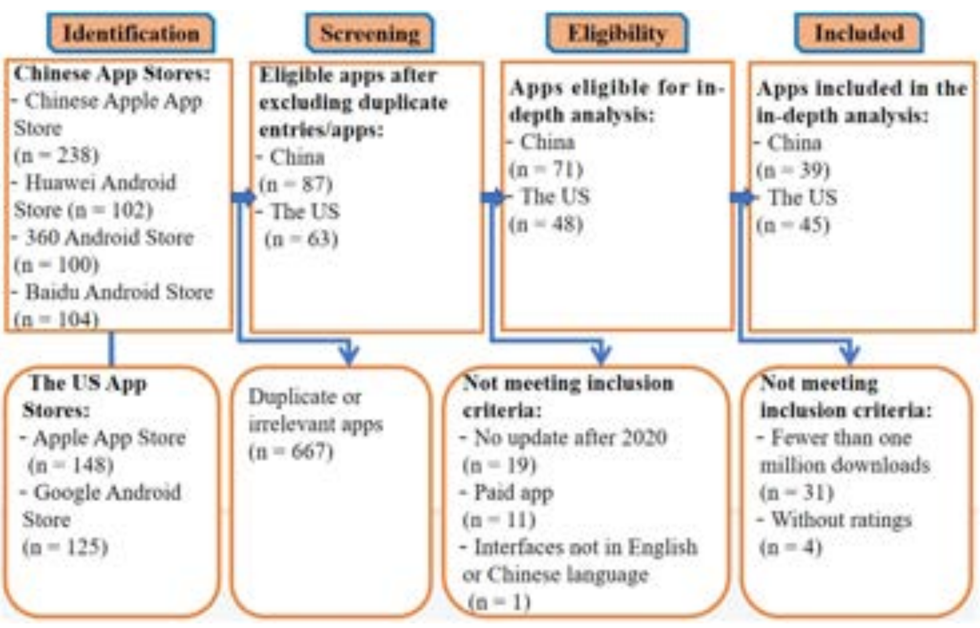

FIGURE 1 | Flowchart of the app selection process.

TABLE 1 | Characteristics of the 84 apps for pregnancy to postpartum care identified in the US–China comparison.

Category	China ($n = 39$)	United States ($n = 45$)	χ^2/F	p
Specifications, *n* (%)				
Medical	4 (10.3)	6 (13.3)	1.158	$p > 0.05$[b]
Health and fitness	31 (79.4)	39 (86.7)		
NA[d]	4 (10.3)	0 (0)		
Acquisition costs, *n* (%)				
Free	26 (66.7)	6 (13.3)	25.200	$p < 0.01$**[b]
In-app purchase	13 (33.3)	39 (86.7)		
Target users (app description accompanying a clear statement), *n* (%)				
Women TTC[a]	18 (46.2)	6 (13.3)	13.64	$p < 0.05$*[b]
Pregnant women	28 (71.8)	32 (71.1)		
Postpartum women	16 (41)	23 (51.1)		
Those providing infant care	16 (41)	1 (2.2)		
Not specified	3 (7.7)	2 (4.4)		
Safety statement, *n* (%)				
With	4 (10.3)	24 (53.3)	17.446	$p < 0.01$**[b]
Without	35 (89.7)	21 (46.7)		
Privacy policy, *n* (%)				
With	35 (89.7)	42 (93.3)	0.039	$p > 0.05$[b]
Without	4 (10.3)	3 (6.7)		
Supporting evidence, *n* (%)				
With	4 (10.3)	23 (51.1)	15.988	$p < 0.01$**[b]
Without	35 (89.7)	22 (48.9)		
Operating system, *n* (%)				
iOS	29 (74.3)	33 (73.3)	26.820	$p < 0.01$**[b]
Android	31 (79.5)	14 (31.1)		
Year of the most recent update, *n* (%)				
2020	10 (25.6)	17 (37.8)	1.411	$p > 0.05$[b]
2021	29 (74.4)	28 (62.2)		
Language, *n* (%)				
Chinese	22 (56.4)	0	63.562	$p < 0.01$**[b]
English	0	36 (80)		
Multiple languages offered	17 (43.6)	9 (20)		
Mean user rating (stars/5)	3.09 ± 0.70	3.41 ± 0.9	3.198	$p > 0.05$[c]

[a] *Trying to conceive.*
[b] *Chi-square test.*
[c] *Analysis of variance.*
[d] *Not available.*
** *Extremely significant difference at p < 0.01.*
* *Significant difference at p < 0.05.*

meditation, treatment for psychosocial concerns, breathing exercises, postpartum pelvic exercises, pregnancy Pilates, or pelvic exercise. The following features were not included in any of the 45 US mobile apps: recording baby photos, pregnancy check-up reminders, recording contractions, recording ovulation date, infant vaccination reminders, recording pregnancy photos, recording temperature, ovulation reminders, recording the baby's weight, or addressing psychosocial concerns.

Our quantitative analysis revealed the following significant differences between China and the US in terms of the functions offered by the PtP care apps. (1) Monitoring: recording fetal size ($n = 18$, 46.2% in China vs. $n = 3$, 6.7% in the US) and tracking physical activity during pregnancy ($n = 6$, 15.4% in China vs. $n = 16$, 35.5% in the US); (2) nutrition: nutrition planning during pregnancy ($n = 15$, 38.5% in China vs. $n = 7$, 15.6% in the US); (3) general education: nutrition knowledge during pregnancy ($n = 15$, 38.5% in the China vs. $n = 5$, 11.1% in the US); (4) exercise: pregnancy yoga ($n = 2$, 5.1% in China vs. $n = 21$, 46.7% in the US), pregnancy workouts ($n = 2$, 5.1% in China vs. $n = 13$, 28.9% in the US), and pregnancy meditation ($n = 0$, 0% in China vs. $n = 10$, 22.2% in the US); (5) community: general communication ($n = 16$, 41% in China vs. $n = 6$, 13.3% in the US) and patient–clinician communication ($n = 14$, 35.9% in the China vs. $n = 0$, 0%); (6) shopping: pregnancy and baby product sales ($n = 11$, 28.2% in China vs. $n = 2$, 4.4% in the US), (7) others: baby stories ($n = 10$, 25.6% in the China vs. $n = 0$, 0% in the US) and baby music ($n = 7$, 17.9% in the China vs. $n = 3$, 6.7% in the US).

App Quality Based on the MARS

The overall MARS scores for app quality ranged from a minimum score of 2.7 to a maximum of 4.4 (median 3.5) in the US vs. 2.3 to 4.2 (median 3.2) in China, with most apps (34/45, 76% in the US vs. 23/39, 59% in China) achieving a score >3. The engagement score ranged from 2.2 to 4.4 (median 3.6) in the US vs. 1.2 to 4.4 (median 2.9) in the China. The functionality score ranged from 3.0 to 4.8 (median 4.0) in the US vs. 2.5 to 4.5 (median 3.7) in the China. The esthetics score ranged from 2.3 to 4.4 (median 3.8) in the US vs. 2.3 to 4.7 (median 3.6) in the China, and the information score ranged from 1.2 to 4.9 (median 2.9) in the US vs. 1.2 to 4.2 (median 2.4) in the China. The mean MARS scores for all 84 analyzed Chinese and US apps are reported in **Supplementary Table 1**.

Risk Assessment of PtP Care Apps in the US and China

The security risks associated with the 84 apps were assessed using the anti-fraud software. Among US mobile apps, 8.9 and 40% were considered high- and medium-risk, respectively; among Chinese apps, 7.6% (3/39) were deemed to be high-risk (**Table 3**). The risk of PtP care apps differed significantly between the US and China ($p < 0.01$; **Table 3**). According to the risk assessment report, "high-risk" generally suggests that the program includes hazardous information or third-party plug-ins, whereas "medium-risk" implies the possibility of personal information leakage.

DISCUSSION

This study systematically demonstrated the features and functionalities of in-store mobile apps for PtP care in the US and China, two of the largest app marketplaces, offering an overview of their primary characteristics and functions with a special emphasis on weaknesses and gaps to be addressed with future eHealth-related innovations. We believe that such an investigation is essential for developing more effective PtP health apps during COVID-19. Pregnancy and postnatal education and support provided by a multidisciplinary team of specialists may

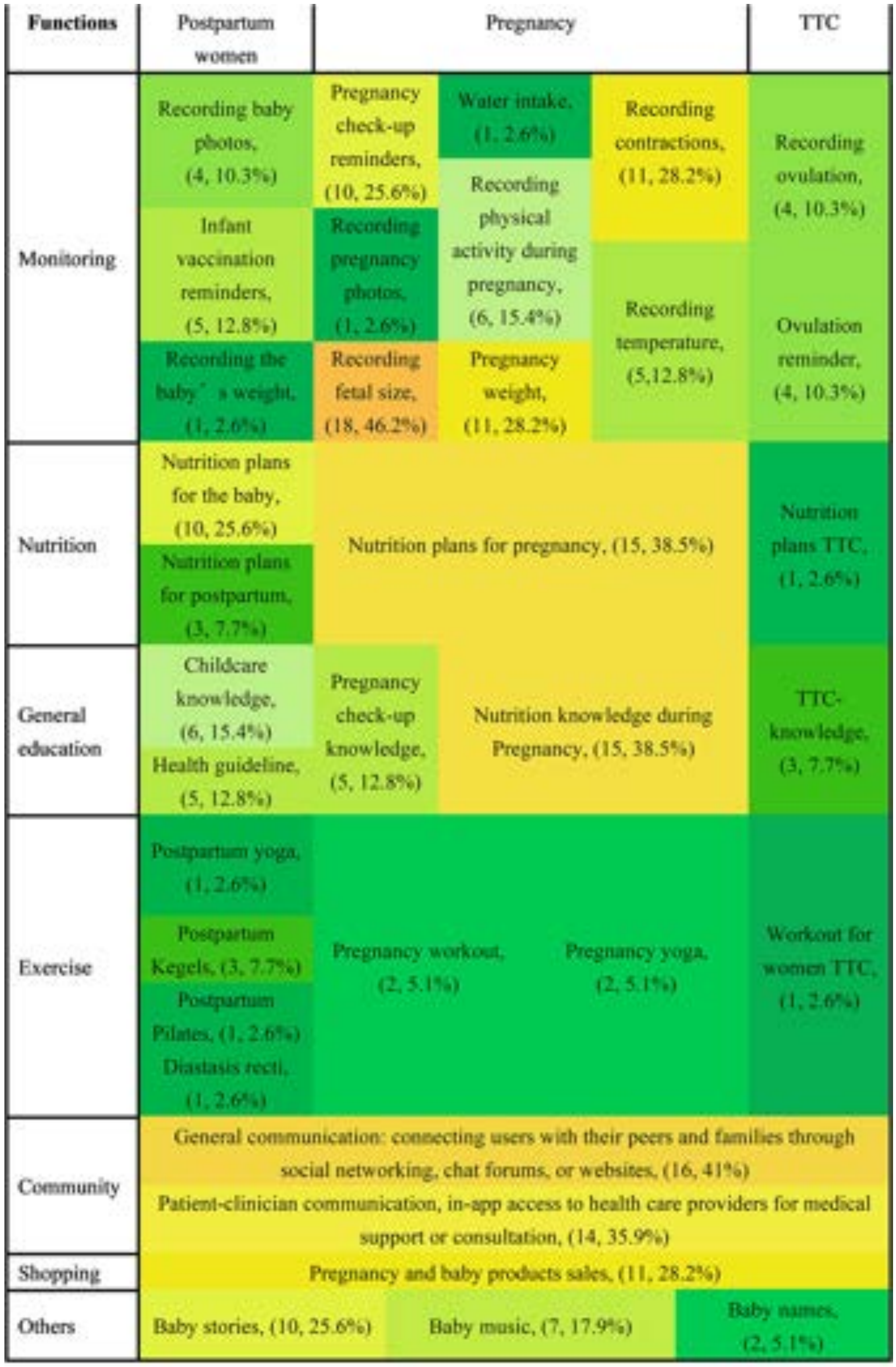

FIGURE 2 | Heat map of features of the 39 Chinese mobile apps for pregnancy to postnatal care. TTC, trying to conceive.

improve the quality of care through apps, even among low-income groups or groups in impoverished areas. Overall, our study reveals that (1) there are differences in PtP care mobile apps between the two countries; (2) the quality and effectiveness of the information offered by apps must be carefully examined and combined with professional medical advice; and (3) some Chinese and US apps were suspected of stealing users' personal information. These findings do not support our hypothesis and highlight key areas for improvement of apps targeted at pregnant and postpartum women.

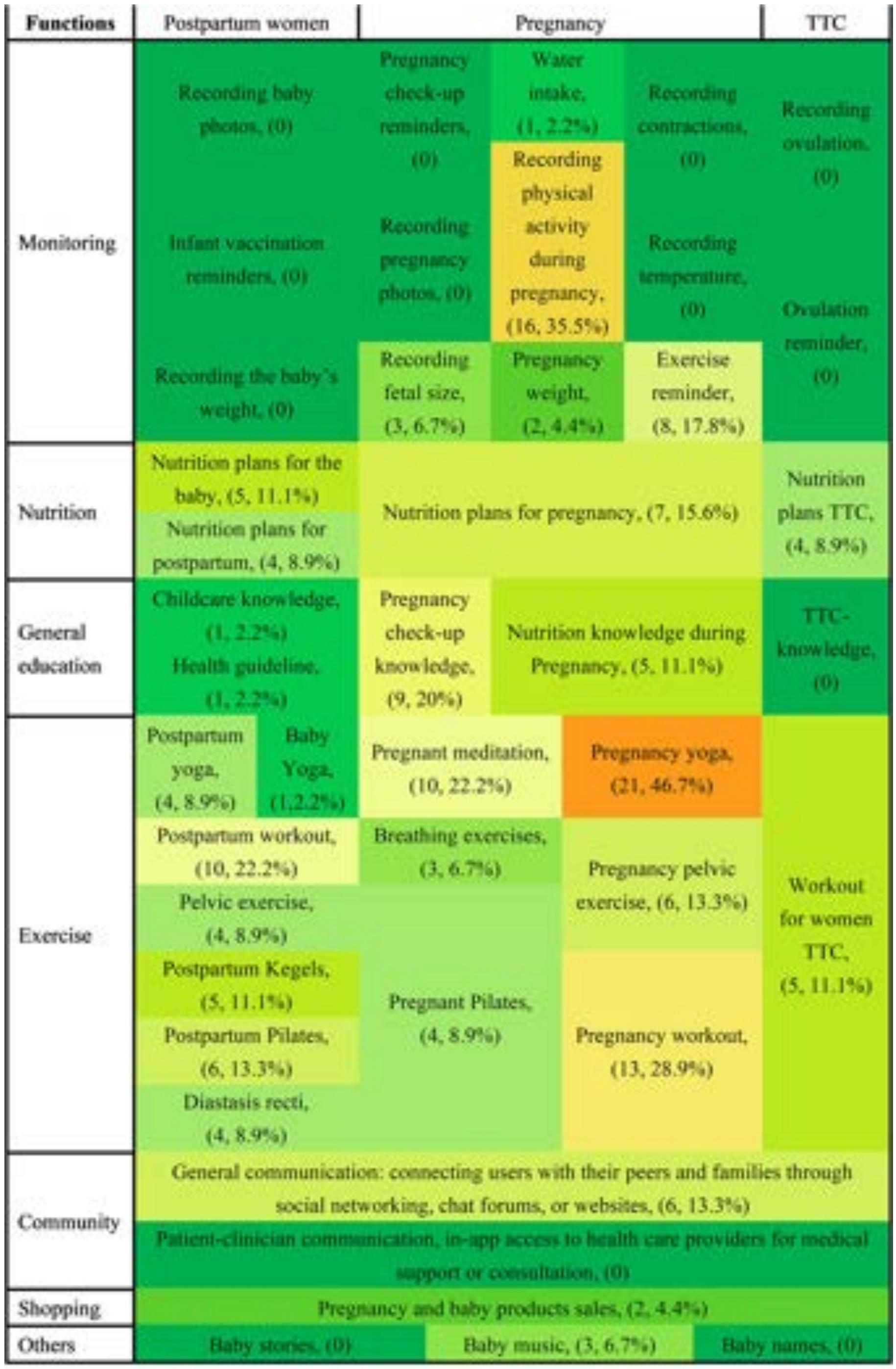

FIGURE 3 | Heat map of features of the 45 US mobile apps for pregnancy and postnatal care. TTC, trying to conceive.

Overview of Hypothesis Validation Findings

Metadata of Apps

All 45 US apps were classified as medical or health and fitness apps, but several Chinese apps (10.3%, 4/39) were uncategorized. This may be because the Food and Drug Administration (FDA) risk studies and policy recommendations for mobile health technology require apps to be categorized into three categories: health management, general management, and medical devices (38). Another possible explanation is that the FDA regulates all mobile health technology (38). Unlike the US, China lacks any such legislation. Additionally, few apps were classified as medical devices, indicating a severe weakness in Chinese–US

TABLE 2 | Comparison of the characteristics of the mobile apps for pregnancy and postnatal care between the US and China.

Category	China ($n = 39$)	United States ($n = 45$)	χ^2	p
Log, *n* (%)				
Recording baby photos	4 (10.3)	0 (0)		
Infant vaccination reminders	5 (12.8)	0 (0)	54.486	$p < 0.01$**
Recording the baby's weight	1 (2.6)	0 (0)		
Pregnancy check-up reminders	10 (25.6)	0 (0)		
Recording pregnancy photos	1 (2.6)	0 (0)		
Recording fetal size	18 (46.2)	3 (6.7)		
Water intake	1 (2.6)	1 (2.2)		
Recording physical activity during pregnancy	6 (15.4)	16 (35.5)		
Exercise reminder	0 (0)	8 (17.8)		
Pregnancy weight	11 (28.2)	2 (4.4)		
Recording contractions	11 (28.2)	0 (0)		
Recording temperature	5 (12.8)	0 (0)		
Recording ovulation	4 (10.3)	0 (0)		
Ovulation reminder	4 (10.3)	0 (0)		
Nutrition, *n* (%)				
Nutrition plans for baby	10 (25.6)	5 (11.1)		
Nutrition plans for postpartum women	3 (7.7)	4 (8.9)	25.200	$p < 0.01$**
Nutrition plans for pregnant women	15 (38.5)	7 (15.6)		
Nutrition plans for women TTC[a]	1 (2.6)	4 (8.9)		
General education, *n* (%)				
Childcare knowledge	6 (15.4)	1 (2.2)		
Health guideline	5 (12.8)	1 (2.2)	91.13	$p < 0.01$**
Pregnancy check-up knowledge	5 (12.8)	9 (20)		
Nutrition knowledge during pregnancy	15 (38.5)	5 (11.1)		
TTC knowledge	3 (7.7)	0 (0)		
Exercise classes, *n* (%)				
Postpartum yoga	1 (2.6)	4 (8.9)		
Postpartum workout	0 (0)	10 (22.2)	95.356	$p < 0.01$**
Pelvic exercise	0 (0)	4 (8.9)		
Postpartum Kegels	3 (7.7)	5 (11.1)		
Postpartum Pilates	1 (2.6)	6 (13.3)		
Diastasis recti	1 (2.6)	4 (8.9)		
Pregnancy meditation	0 (0)	10 (22.2)		
Pregnancy yoga	2 (5.1)	21 (46.7)		
Pregnancy pelvic exercise	0 (0)	6 (13.3)		
Pregnancy workout	2 (5.1)	13 (28.9)		
Pregnancy Pilates	0 (0)	4 (8.9)		
Workout for women TTC	1 (2.6)	5 (11.1)		
Community, *n* (%)				
General communication	16 (41)	6 (13.3)		
Patient–clinician communication	14 (35.9)	0 (0)	8.288	$p < 0.01$**
Shopping, *n* (%)				
With shopping function or service	11 (28.2)	2 (4.4)	9.017	$p < 0.01$**
Others, *n* (%)				
Baby stories	10 (25.6)	0 (0)		
Baby music	7 (17.9)	3 (6.7)	35.122	$p < 0.01$**
Baby names	2 (5.1)	0 (0)		

[a] *Trying to conceive.*
** *Extremely significant difference at $p < 0.01$.*

apps. To overcome this issue, apps must not only be designed as information or entertainment tools but also be subjected to new medical device legislation. This legislation emphasizes the importance of anticipating the use of medical device apps by mothers and the role of these apps in controlling or assisting conception (39, 40). Furthermore, each Chinese app covered a broader range of target users than US apps. Three Chinese apps and two US apps did not specify their target users. By contrast, a few more US apps noted that it was vital for app developers to differentiate their products to match the specific demands of diverse populations (41). A previous study reported that pregnant and postpartum women in China had considerably different demands than did women in the US (5), which may explain the difference in target users.

Regarding supporting evidence and safety statements, only 10.3% of the Chinese apps offered references to the information provided and recognized their scientific responsibility. The mean value of the information was lower than the acceptable level in both the US and China. Pregnant and postpartum women may be more vulnerable to inaccurate information (26). Given the potential of mHealth apps to promote maternal health and knowledge about pregnancy and children's health and development, apps capable of providing the most comprehensive, accurate, and trustworthy information on pregnancy and the postnatal period are urgently needed.

Regarding acquisition costs, ∼80% of US apps offered in-app purchases; this was connected to the difference in the exercise functions, as American apps offered plentiful training courses for pregnancy and exercise-related postpartum recovery. Exercise during pregnancy is increasingly popular in the US (42, 43), which may explain the large disparity in acquisition costs between the two countries. The addition of the fitness element in US apps is a worthwhile endeavor, particularly amid the current COVID-19 outbreak. Effective online prenatal exercise classes are useful to both mothers and their unborn children (11). Noticeable distinctions were observed between Chinese and US apps in terms of the operating system and language. Chinese apps tend to offer multiple languages and favor Android operating systems compared to their US counterparts. This may be related to China's increasing mobile market share in domestic and foreign markets in recent years (44).

User feedback is a true reflection of users' requirements and genuine experiences using the app (45, 46). Objective app quality reflects the app's information, functionality, aesthetics, and engagement (47). Both countries' user and objective app quality ratings were at acceptable levels, with the US marginally outperforming China in these categories and the engagement score of quality being poor in China. The development of PtP apps may be improved if the apps are highly valued and used by the target audience (46). The abovementioned results did not support our hypothesis that the most updated content offered by the app would be high-quality and effective. This suggests that the features of apps available in both the US and China should be improved, and more interaction between app developers and users is recommended.

TABLE 3 | The risk assessment of pregnancy and postnatal care mobile apps in the US and China.

Risk	United States ($n = 45$), n (%)	China ($n = 39$), n (%)	p-value
Low	23 (51.1)	4 (10.3)	$p < 0.01$**
Medium	18 (40)	32 (82.1)	$p < 0.01$**
High	4 (8.9)	3 (7.6)	$p > 0.05$

**Extremely significant difference at $p < 0.01$.

Functions and Modules

According to our data, monitoring, nutrition, general education, exercise, community, shopping, and other features were the most utilized functions in prenatal care mobile apps in both China and the US. However, psychological services were seldom observed in either country's apps, even though psychological support is strongly related to pregnant and postpartum women's mental health (48). The primary impediment to developing this function and module may be its complicated nature (49).

Exercise-related features (e.g., pregnancy yoga, fitness, and meditation) were more frequent in US-based apps than in Chinese-based apps. We have already discussed the reasons for the discrepancies in the exercise modules during the pregnancy and postpartum periods. Research has demonstrated that exercise is beneficial during pregnancy (50), but because of a lack of funds and expert advice, many pregnant women do not achieve the recommended amount of physical activity (51, 52). Therefore, we propose that the Chinese apps should be upgraded to incorporate exercise modules to effectively address the aforementioned issues because online courses are less expensive than courses offered at professional organizations. This ensures that even in impoverished regions and during the COVID-19 lockdown, users can access relevant exercise modules (53).

Monitoring functionalities (e.g., tracking fetal size, physical activity during pregnancy, and contractions) were more common in Chinese apps than in US apps. These services are based on built-in algorithms (generally predictive modeling utilizing acquired personal data and possibly sophisticated methods, such as artificial intelligence) and provide users with immediate and direct advice depending on their circumstances (54). These functionalities play a crucial role, as offline healthcare may be unavailable during the COVID-19 pandemic (55). However, monitoring modules should be constructed with care and prudence, and further attempts with alternative algorithms should be encouraged simultaneously. The study findings also revealed that none of the apps directly enabled mothers to schedule appointments for medical treatment, immunization, or physical examinations, highlighting the absence of a direct link between apps and appointment scheduling systems. We recommend that PtP care apps be connected to a wider regional or national public health care network. This substantial gap could be solved by developing more networked and institutional apps to improve booking processes by lowering the number of calls or other request types from patients and the professionals that manage them (56).

Risk Assessment

Risk assessment is primarily concerned with two factors: the content and the app program. The content risk evaluation was primarily based on information quality, security statements, and scientific evidence. According to the findings of the information quality, supporting scientific evidence, and safety statement inquiries, the content-related risk was mostly due to a lack of safety statements and published scientific literature or had positive outcomes in studies that are not RCTs. This issue was more prominent in Chinese apps than in US apps. The app program checks revealed that several of these apps required the user to provide personal information beyond the extent of their permissions. The app self-examination by the national anti-fraud center measured the security of the installation package and program usage. The report demonstrated that certain apps compelled users to provide permission, claimed too many privileges, and gathered personal information that was outside of their scope. Analysts noted that mobile apps have a strong competitive edge in the market; apps would be unlikely to work if users do not accept the privacy policies (57). The above information does not support our hypothesis that all apps would be concerned with users' personal information and data privacy and security. We propose that users carefully read the privacy statements and that government agencies improve internet surveillance.

Strengths and Limitations

Several benefits and drawbacks of the present study should be considered when evaluating the conclusions. To the best of our knowledge, this study is the first to evaluate the quality and risks associated with in-store PtP care apps in China and the US. Second, we acted as users at various PtP stages to download and utilize the apps, which may or may not have resulted in overlooking functional information about the mobile apps. Third, the consistency and dependability of the data gathered were rigorously evaluated before being used. Finally, apps available in two countries with distinct cultures, healthcare systems (58, 59), and economic standings were analyzed. This study also has several drawbacks. First, we identified apps at a single time point, which may have omitted longitudinal updates to app features. Second, given the nature of the characteristics under investigation based on the user ratings, subjectivity in assigning ratings cannot be ruled out. Third, we excluded paid apps, which may have omitted some available information. Finally, we did not include apps from other countries because of linguistic barriers. Future researchers interested in this topic may wish to investigate different time periods to increase the reliability of longitudinal comparisons on functionality and technological aspects in more countries. Additionally, we will further analyze the influence of PtP apps on PtP health care.

CONCLUSIONS

In summary, the in-store mobile PtP care apps differed between China and the US regarding their functionality and characteristics. Both countries' apps, and particularly Chinese apps, have their share of issues; these include lack of evidence-based information, risk of inaccurate content, and lack of app evaluation. Monitoring-related information was more common in Chinese apps, whereas exercise-related content was more abundant in US apps. Both countries' apps also failed to provide adequate mental health services. These findings highlight the need for improving the features of PtP care apps available in both countries, and extensive interaction between app developers and users is suggested. Maintaining a suitable level of regulation is necessary to ensure the quality and functionality of in-store apps. Basic public health services for women's health may improve with the development of high-efficiency PtP apps.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

HY: conceptualization, funding acquisition, software, validation, visualization, and writing—original draft. HY, JH, XW, WY, and BS: data curation and formal analysis. HY and JH: methodology. HY and AS: project administration, resources, supervision, writing—review, and editing. All authors revised and approved the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.826896/full#supplementary-material

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Quality assessment of pre- and postnatal nutrition and exercise mobile applications in the United States and China

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Background: Mobile applications (apps) are becoming increasingly prevalent as tools for improving maternal health behaviors. However, the recently updated content and quality of these apps remain unknown. This research investigated the fundamental characteristics, functional modules, and overall quality of maternal apps available in the United States and China to reveal critical nutrition and physical activity gaps.

Methods: A systematic search was performed in Android and iOS app stores (China and the United States). Apps were eligible if they targeted pregnant or postpartum women, focused on nutrition or physical activity, and had interfaces in English or Chinese. The basic characteristics, functional modules, and overall quality of the apps were evaluated, and differences between apps available in China or the United States were determined using analysis of variance and chi-square tests. Pearson correlations were utilized to investigate links between objective quality and user rating.

Results: A total of 65 maternity-related nutrition and physical activity apps (34 from China and 31 from the United States) were eligible. Among them, 68% (21/31) of US apps and 56% (19/34) of Chinese apps did not provide supporting evidence for their content. A greater number of Chinese apps provided app-based general education modules, namely food nutrition knowledge (n = 0, 0% in the United States vs. n = 30, 88.2% in China). Meanwhile, a greater number of US apps provided exercise modules, namely pregnancy yoga (n = 21, 67.7% in the United States vs. n = 2, 5.9% in China). The overall app quality rating in the United States was lower than it was in China (mean: 3.5, SD: 0.6 in China vs. mean: 3.4, SD: 0.7 in the United States). There was no relationship between the overall app quality rating and the user rating in either country (rho = 0.11 in China and rho = −0.13 in the United States).

Conclusion: The characteristics and functional modules of in-store apps for maternal nutrition and physical activity differed between the United States and China. Both countries' apps, especially Chinese apps, lacked evidence-based information, and there was no correlation between app quality and user rating. The results therefore suggest that user ratings cannot be used as an objective indicator of app quality and that it is necessary to improve the empirical basis and credibility of apps in both countries.

KEYWORDS

maternity applications, models, quality, nutrition, physical activity

1. Introduction

Women's health is at its most susceptible during the pregnancy to postpartum (PtP) stages (1, 2). Unhealthy eating habits and physical inactivity are prominent health risk factors throughout the PtP stages. They may cause both short- and long-term health issues for women (3, 4), such as the need for obstetric intervention (e.g., cesarean section and instrumental delivery) (5), a greater likelihood of fetal macrosomia (i.e., a large-for-gestational-age baby) (6), a greater risk of pregnancy-related complications (e.g., gestational diabetes, hypertension, pre-eclampsia) (7), and poor cardiovascular health (8).

Some studies have found that obtaining the appropriate amount of nutrition and physical activity (N&PA) throughout the PtP period is crucial for the health of both mother and newborn as well as for the long-term health of both mother and child (9–12). Consequently, the amount of N&PA required at each phase of PtP must be meticulously planned and managed to reduce the incidence of complications. However, recent researches in Canada and Australia suggested that fewer than 50% of women receive suitable guidance from professionals about healthy N&PA during the PtP period (13, 14). This might be due to healthcare being too expensive or inaccessible in low-income regions (15) or to the coronavirus pandemic (COVID-19) and associated isolation periods (16, 17).

The tremendous surge in popularity of mobile health (mHealth) and electronic health (eHealth) has changed the conventional model of healthcare services in recent years (18). More people consult health and lifestyle information *via* mobile applications (apps), which have the potential to significantly improve current therapy and minimize reliance on professional team health services (19, 20). For instance, 81% of Chinese (21), 75% of Australian (22), and 93% of Swiss (23) prenatal and postnatal women reported using at least one prenatal and postnatal app, with more than a quarter reporting that learning about N&PA was the primary reason for doing so. Furthermore, health-related apps have contributed to safe social distancing and lower infection rates during the COVID-19 pandemic and its associated isolation periods (24). As these apps have become essential digital resources for accessing N&PA guidance throughout the PtP period, increasing amounts of research have been devoted to assessing their quality and efficacy to ensure that women receive appropriate guidance. Meanwhile, the Mobile Application Rating Scale (MARS), a reliable, multi-dimensional, simple, and objective tool, was thus developed to classify and evaluate the quality of mobile health apps. It may be used to provide a checklist for designing and developing new high-quality health apps (25).

Evidence from systematic reviews and randomized controlled trials (RCTs) suggests that pregnancy and postpartum apps are generally effective in promoting maternal and newborn physical health (e.g., weight management, postpartum recovery, and infant care) (7, 12, 26). In addition, their cost-effectiveness and convenience have been beneficial during the COVID-19 pandemic (27). Nevertheless, the apps quality (esthetics, functionality, information, and engagement) varies significantly. Many lack supporting RCTs, rigorous evaluation procedures, or published protocols and generally show an absence of quality assessment (17, 28). However, new users still choose to download such apps, and research has shown that user feedback (subjective quality) is more influential in convincing new users to download an app than RCTs and scientific evidence (29). The correlation between user feedback and app quality is particularly important for new users to choose high-quality apps. Unfortunately, the correlation between user feedback and app quality has not been thoroughly investigated based on previous studies. Furthermore, most research on these apps was conducted before 2020, and previous reviews of N&PA apps have tended to focus on pregnant women while disregarding the pre-conception and the postpartum period (21, 30, 31). Finally, some reviews evaluating the information and quality of apps restricted their search to those available in their respective country's app store (30, 32–34). Consequently, many frequently used apps may have been excluded, thereby limiting the conclusions that can be drawn from the results.

Previous research on the effect of N&PA apps during the PtP period revealed that the influence of mobile apps on prenatal and postnatal women's lifestyle, health, and decision-making is significant. However, data from RCTs on this subject are still insufficient. Noteworthy gaps in the current research were also exposed. First, the quality and efficacy of recently updated PtP N&PA apps are unknown, which may hinder health improvement, as misinformation about N&PA could lead to inappropriate decision making and increase the risk of adverse health outcomes during the perinatal period (35). Second, the link between user rating and app quality rating has been ignored; as a quick way to judge the quality of an app, user ratings help drive new users to download them (36). Third, commonly used apps may have been missed.

To address the above-mentioned gaps, the aims of this study were (1) to describe and analyze the characteristics and functional modules of PtP N&PA apps in the United States and China, two of the largest app markets; (2) to comprehensively evaluate the overall quality of PtP N&PA mobile apps; and (3) to investigate the connection between app quality rating and user rating. We hypothesized that (1) the recently updated information offered by apps would be consistent with N&PA guidelines in PtP period; (2) PtP N&PA apps in the United States and China would have comparable characteristics and functional modules; and (3) there would be a link between app quality and user rating.

2. Materials and methods

2.1. Search strategy

A systematic search was performed in Tencent My App (China), Huawei App Market (China), 360 Mobile Assistant (China), Apple App Store (China and the United States), and Google Play (United States) from January 3 to February 27, 2022. Apps were searched using the following keywords: "diet," "food," "nutrition," "supplement," "food intake," "nourishment," "healthy eating," "food safety," "snack," "soft drink," "carbonated beverages," "vegetarian," "nutrition recommendations," "nutrition guidelines," "vegan," "fruit," "vegetable," "physical activity," "physical fitness," "exercise," and "sport" in both the Chinese and English languages. To narrow the results, each search word was combined with "pregnancy," "pregnant," and "postpartum."

2.2. Selection process

The apps included in this research were defined as those that provided any dietary or physical activity content related to the pre-conception, pregnancy, or postpartum periods. In the preliminary search list, only apps with >1 million installations were included. According to user feedback, consumers are less inclined to pick and install mobile apps with fewer downloads than this (29). The following apps were excluded: (1) those without a rating; (2) those without a Chinese- or English-language interface; (3) those without detailed function description and content introduction in the app store; (4) unrelated and duplicate apps; (5) paid apps with no trial period; (6) those with no updated version since December 31, 2019; and (7) those with <1 million installations.

2.3. Data extraction

Two independent researchers selected the apps for study inclusion based on the eligibility criteria. Apps that fulfilled the inclusion criteria were downloaded on either an iPhone or an Android device. The researchers collected the following information from each of the eligible apps: developer, name, app category, latest update date, in-app purchase, target audience, app store, safety statement, privacy policy, evidence-based information (i.e., RCTs or published scientific literature information of app were provided in the app introduction or in the content of the app or the app official website), languages, average user rating, and app functionalities (Note: the preview or function description in the app store would be a reference if the developer had not set up the functional module partition). To prevent data loss, each researcher compiled the above information in a standard spreadsheet. Inconsistencies in extracted data between the researchers were addressed through discussion or consultation with a third researcher.

2.4. Content analyses

The Mobile Application Rating Scale (MARS) was used to assess app quality across four dimensions: engagement (five items), functionality (four items), esthetics (three items), and information quality (seven items) (37). The MARS subjective quality subscale is based on the user rating as a subjective evaluation of the user experience. All MARS elements were rated using a five-point Likert scale (1 = inadequate to 5 = excellent) (37). Overall app quality rating was measured by averaging the four dimensions, with each dimension's mean score used to calculate the overall mean score (37). Apps with a MARS score of three or more but less than four were considered to be of satisfactory quality, while those with scores of four or more were considered to be of high quality (25). Six MARS-trained researchers were assigned an equal number of apps to independently assess app quality using MARS and record the functionalities. All researchers registered each included app to record functionalities, assess and rate its functionality, engagement, esthetics, and information quality and to ensure that each app element was evaluated. A simulated data set of the beginning of the preceding menstrual cycle and an expected delivery date were inputted where relevant to correctly evaluate the potential of the apps. Two researchers acted in the first trimester, two in the second trimester, and two in the third trimester to fully review an app's functionality throughout pregnancy. All the researchers gathered and evaluated data from the trying to conceive (TTC) and postpartum periods. Each researcher used the same spreadsheet to record the primary and secondary functionalities of each module after signing into the app. Between February 28 and March 20, 2022, the researchers gathered and evaluated data on the apps' basic characteristics, functional modules, and quality. Considering the influence of researcher's subjective perception, the reliability of the data collected by the six researchers was examined using the Fleiss Kappa value, with a Kappa value <0.2 indicates poor consistency, 0.2∼0.4 indicates average consistency, 0.4∼0.6 indicates moderate consistency, 0.6∼0.8 indicates strong consistency, and 0.8∼1 indicates very strong consistency (38). The researchers discussed disparities and uncertainties among the in-app ratings to come to an agreement on the final MARS scores.

2.5. Statistical analyses

Origin (2021) (Northampton, MA, USA) was used to calculate the frequency of basic characteristics and functional modules, and Statistica (version 14.0) was used to conduct Kolmogorov-Smirnov test, an analysis of variance (ANOVA), and chi-square test. The Statistical Product and Service Solutions (SPSS) version 26.0 was used to calculate the Fleiss Kappa value for the consistence of data collected by six researchers. ANOVA was used to examine the user rating difference between the Chinese and US apps, with a significant threshold of 0.05. A chi-square test was used to examine the characteristics and functionality differences between the Chinese and US apps with a significance threshold of 0.05. The associations between overall app quality rating and user rating were examined using Pearson correlations with significance thresholds set at $p < 0.05$.

3. Results

3.1. App selection

Based on the search strategy, 1,444 apps were identified and screened in Tencent My App, Huawei App Market, 360 Mobile Assistant, Apple App Store, and Google Play; 1,379 were excluded, with one of the Chinese apps excluded through discussion with a third researcher since the two researchers had different viewpoints after comparing two Chinese apps with different names and developers but the same content and functions. After further exclusions, a total of 65 apps (31 from the United States and 34 from China) were included (**Figure 1**).

3.2. Basic characteristics

Table 1 summarizes the basic characteristics of all the included apps. The Kolmogorov-Smirnov test results showed that all the analysis items were not significant ($p > 0.05$), indicating a normal distribution. In the United States, all the apps were categorized by the app stores: 74.2% (23/31) were categorized as "health and fitness," while just 9.7% (3/31) were labeled as "medical." An in-app update comparison found no substantial difference between the US and Chinese apps ($p > 0.05$). Regarding in-app purchase, the US app stores had a higher percentage of in-app purchases than did those in China: 71% (22/31) in the United States vs. 32.3% (11/34) in China; $p < 0.01$. The average user rating of US apps was significantly lower than that of Chinese apps: mean = 3.4 in the United States vs. mean = 3.8 in China; $p < 0.05$. In China, 8.8% (3/34) of mobile apps were categorized as "medical" and 55.9% (19/34) as "health and fitness," while 2.9% (1/35) were unclassified. A total of 47.1% (16/34) of Chinese mobile apps lacked explicit privacy policy and safety statements, while 80.7% (25/31) of US apps supplied clear safety statements ($p < 0.05$), and 87.1% (27/31) provided a privacy policy ($p < 0.01$). Further, a greater proportion of Chinese apps than US apps targeted breastfeeding mothers and babies [lactating women: 73.5% (25/34) in China vs. 3.2% (1/31) in the US; baby: 79.4% (27/34) in China vs. 3.2% (1/31) in the US; $p < 0.01$]. Multiple language support was present in just 8.8% (3/34) of Chinese apps but 25.8% (8/31) of US apps ($p < 0.01$).

3.3. Functional modules

The primary and secondary functionalities of each module supplied by the US and Chinese apps are depicted in **Figure 2**. Both US and Chinese PtP N&PA apps included seven common modules (general education, exercise, monitoring, shopping, community, nutrition, and others) and five categories of targeted users (men TTC, women TTC, infant, pre- and postpartum women). The comparison of functional modules supplied by the US and Chinese apps is depicted in a bubble chart (**Figure 3**). Analysis items conform to a normal distribution ($p > 0.05$). Pregnancy yoga was the most prevalent course of exercise module among the 31 US apps (n = 21, 67.7%), followed by calorie tracking in monitoring module (n = 18, 58.1%) and pregnancy-related exercise taboo knowledge in general education module (n = 16, 51.6%). Food nutrition knowledge in general education module was the most prevalent content among the 34 Chinese apps (n = 30, 88.2%), followed by nutritional effectiveness of food (n = 28, 82.4%) and pregnancy-related exercise taboo knowledge (n = 27, 79.4%). None of the 34 Chinese apps contained the following components: recording the baby's height, documenting coffee consumption, recording TTC weight, setting a folic acid reminder, nutrition knowledge during pregnancy with type 2 diabetes, nutrition knowledge for weight management during pregnancy, pelvic exercises during pregnancy, breathing exercises during pregnancy, or meditation during pregnancy. The following components were not available in any of the 31 US apps: pregnancy image recording, pregnancy check-up reminders, nutrition knowledge for lactating women,

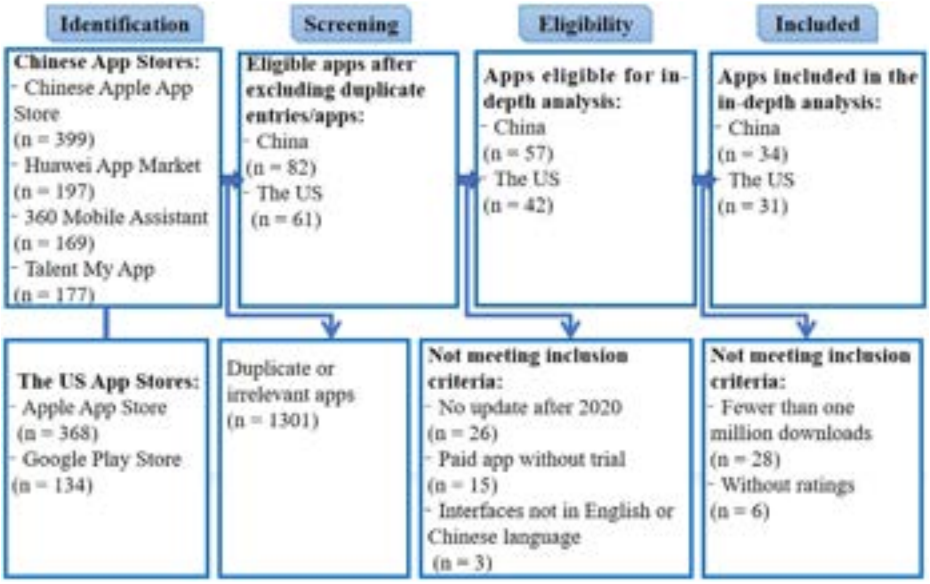

FIGURE 1
Flowchart of the selection process for apps included in the review.

TTC nutrition knowledge for males, nutrient intake amount knowledge, food nutrition knowledge, or baby music.

The ANOVA results indicated the following significant disparities in modules between the US and Chinese apps: (1) general education: pregnancy diet taboo knowledge (n = 7, 22.6% in the United States vs. n = 18, 52.9% in China), nutrition knowledge for women TTC (n = 10, 32.3% in the United States vs. n = 1, 2.9% in China), nutrition knowledge during pregnancy with type 2 diabetes (n = 5, 16.1% in the United States vs. n = 0, 0% in China), food nutrition knowledge (n = 0, 0% in the United States vs. n = 30, 88.2% in China); (2) nutrition: recipe recommendations (with nutrition facts and steps) (n = 15, 48.4% in the United States vs. n = 24, 70.6% in China); (3) exercise: meditation during pregnancy (n = 10, 32.3% in the United States vs. n = 0, 0% in China), pregnancy yoga (n = 21, 67.7% in the United States vs. n = 2, 5.9% in China), and pregnancy workouts (n = 13, 41.9% in the United States vs. n = 0, 0% in China) ($p < 0.01$) (Figure 2).

3.4. App quality

Inter-rater reliability for the four dimensions of app quality was satisfactory (Kappa value = 0.79). The overall MARS ratings for app quality ranged from 2.7 to 4.7 (mean: 3.5, SD: 0.6) in China vs. 1.8 to 4.5 (mean: 3.4, SD: 0.7) in the United States, with the majority of apps (21/31, 67.7% in the United States vs. 29/34, 85.3% in China) scoring at or above three ($p > 0.05$). The engagement score ranged from 2.8 to 5 (median 3.6, SD: 0.8) in China vs. 1.6 to 4.2 (mean 3.2, SD: 0.8) in the United States ($p > 0.05$). The functionality score ranged from 2.8 to 4.8 (mean 3.7, SD: 0.6) in China vs. 1.8 to 4.8 (mean 3.7, SD: 0.8) in the United States ($p > 0.05$). The esthetics score ranged from 2.3 to 5 (mean 3.7, SD: 0.7) in China vs. 1.7 to 5 (mean 3.4, SD: 0.9) in the United States, and the information score ranged from 2.2 to 4.4 (mean: 3.2 SD: 0.7) in China vs. 1.7 to 4.5 (mean 3.1, SD:0.9) in the United States ($p > 0.05$). The Kolmogorov-Smirnov test results showed that overall app quality, engagement, functionality, esthetics, and information scores were not significant ($p > 0.05$), indicating a normal distribution. The functionality, esthetics, and information scores varied significantly in the Chinese apps, and a significant difference between functionality and information scores was identified in the US apps ($p < 0.05$) (Figure 4). Supplementary Table 1 presents the mean MARS scores for all 65 assessed apps from the United States and China.

3.5. Relationship between app quality and user rating

Analysis items conform to a normal distribution ($p > 0.05$). The Pearson correlation coefficient between the overall app quality, MARS sub-score categories (engagement, functionality, esthetics, and information), and subjective quality (user rating) in China and the United States is shown in Figure 5. Except for the functionality quality score in the United States (rho = 0.37, $p < 0.05$), the user rating was not significantly correlated with the overall MARS score or sub-scores ($p > 0.05$) in either the US or Chinese apps.

TABLE 1 Characteristics of the 65 nutrition and physical activity apps for prenatal through postpartum evaluated in a United States–China comparison.

Category	China (n = 34)	United States (n = 31)	χ^2/F	P
Specifications, n (%)				
Food and drink	9 (26.47)	5 (16.13)	4.395	$p > 0.05$[2]
Health and fitness	19 (55.88)	23 (74.19)		
Education	1 (2.94)	0		
Life	1 (2.94)	0		
Medical	3 (8.82)	3 (9.68)		
NA[4]	1 (2.94)	0		
In-app purchase, n (%)				
With	11 (32.35)	22 (70.97)	9.674	$p < 0.01$**[2]
Without	23 (67.65)	9 (29.03)		
Target users (app description accompanied by a clear statement), n (%)				
Women TTC[1]	3 (8.82)	9 (29.03)	36.744	$p < 0.01$**[2]
Men TTC	2 (5.88)	0		
Baby	27 (79.41)	1 (3.23)		
Lactating women	25 (73.53)	1 (3.23)		
Pregnant women	26 (76.47)	13 (41.94)		
Postpartum women	28 (82.35)	24 (77.42)		
Safety statement, n (%)				
With	18 (52.94)	25 (80.65)	5.558	$p < 0.05$*[2]
Without	16 (47.06)	6 (19.35)		
Privacy policy, n (%)				
With	18 (52.94)	27 (87.10)	8.880	$p < 0.01$**[2]
Without	16 (47.06)	4 (12.90)		
Evidence-based information, n (%)				
With	15 (44.12)	10 (32.26)	0.964	$p > 0.05$[2]
Without	19 (55.88)	21 (67.74)		
Operating system, n (%)				
iOS and Android iOS	12 (35.29) 10 (29.41)	8 (25.81) 13 (41.94)	1.237	$p > 0.05$[2]
Android	12 (35.29)	10 (32.26)		
Year of the most recent update, n (%)				
2020	12 (35.29)	5 (16.13)	0.039	$p > 0.05$[2]
2021	16 (47.07)	20 (64.52)		
2022	6 (17.64)	6 (19.35)		
Language, n (%)				
Chinese	31 (91.18)	0	37.670	$p < 0.01$**[2]
English	0	23 (74.19)		
Multiple languages offered	3 (8.82)	8 (25.81)		
Mean user rating (stars/5)	3.75 ± 0.25	3.39 ± 0.77	6.414	$p < 0.05$*[3]

[1]Trying to conceive.
[2]Chi-square test.
[3]Analysis of variance.
[4]Not available.
**Extremely significant difference at $p < 0.01$.
*Significant difference at $p < 0.05$.

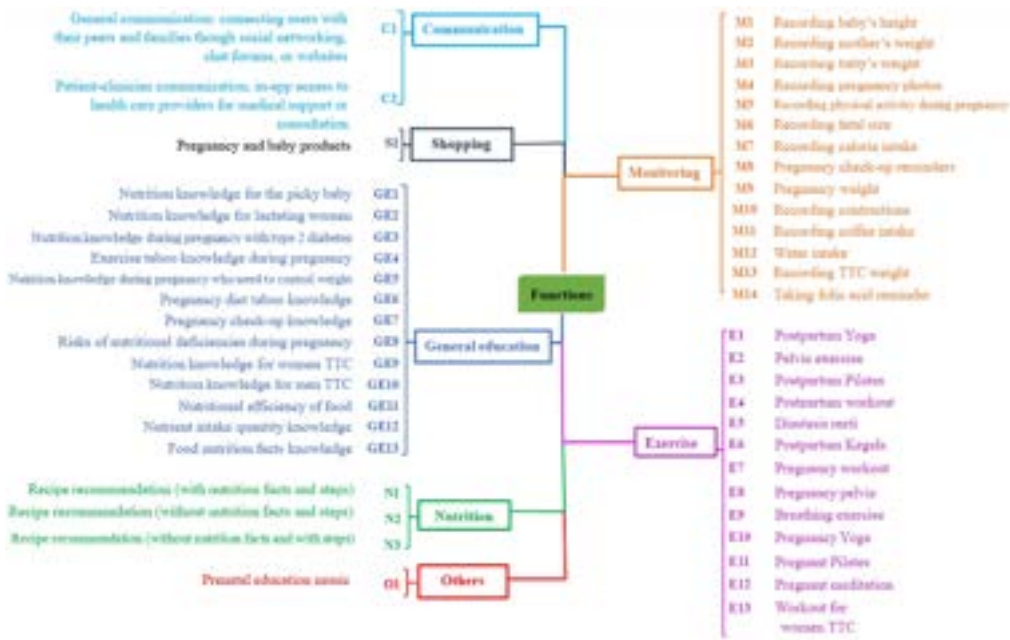

FIGURE 2
The mind map depicts the primary and secondary models available in the United States and Chinese apps. TTC, trying to conceive.

4. Discussion

This research examined the basic characteristics and functionalities of in-store mobile apps for PtP N&PA in the United States and China, two of the major app markets. The study provides an overview of their key characteristics and functions, focusing on flaws and gaps to be addressed in future eHealth-related innovations. We consider such a survey to be crucial for designing or updating new high-quality maternal N&PA apps during the COVID-19 pandemic. Through apps, prenatal and postnatal education and support offered by a multidisciplinary team of professionals can provide suitable guidance on healthy N&PA throughout the PtP period. In summary, our research demonstrates that (1) there are significant disparities in PtP N&PA apps between the United States and China; (2) the apps from both countries faced the challenges of lacking evidence-based information; and (3) user rating and overall app quality are unrelated. These findings contradict our predictions and point to critical areas for improvement in N&PA apps for pre- and postpartum women.

4.1. Hypothesis validation results overview

4.1.1. App-specific metadata

All 31 US apps were divided into three categories: food and drink, health and fitness, and medical (Table 1). Several Chinese apps were education- and life-based, with one remaining uncategorized. A possible explanation for these discrepancies is that the US Food and Drug Administration (FDA) has established regulatory guidelines for classifying mobile health apps into health management, general management, or medical devices categories (39). Unlike in the United States, Chinese regulations governing mobile apps remain in the trial implementation. Additionally, there are over 400 Android app stores in China, making it difficult to standardize categorization criteria. Furthermore, each Chinese app catered to a wider spectrum of consumers than equivalent US apps. As a result, the developers of US apps should customize their products to meet the needs of a wider range of populations. According to recent research, the demands of Chinese pregnant and postpartum women are significantly different from those of US women, especially confinement in childbirth in China, which may account for the disparities among target users (40). Additionally, two Chinese apps evaluated in this research specifically targeted TTC male users. Studies indicated sperm quality in men is significant important for fetal health, and moderate exercise and dietary supplements could effectively increase sperm quality in males TTC (41). The development of N&PA programs for TTC male users is therefore necessary.

An absence of privacy policies and safety statements was more pronounced among Chinese apps than US apps, with nearly half of all assessed Chinese apps lacking a privacy policy or safety statement (Table 1). In recent years, illicit data gathering, data leakage, and online crimes based on user

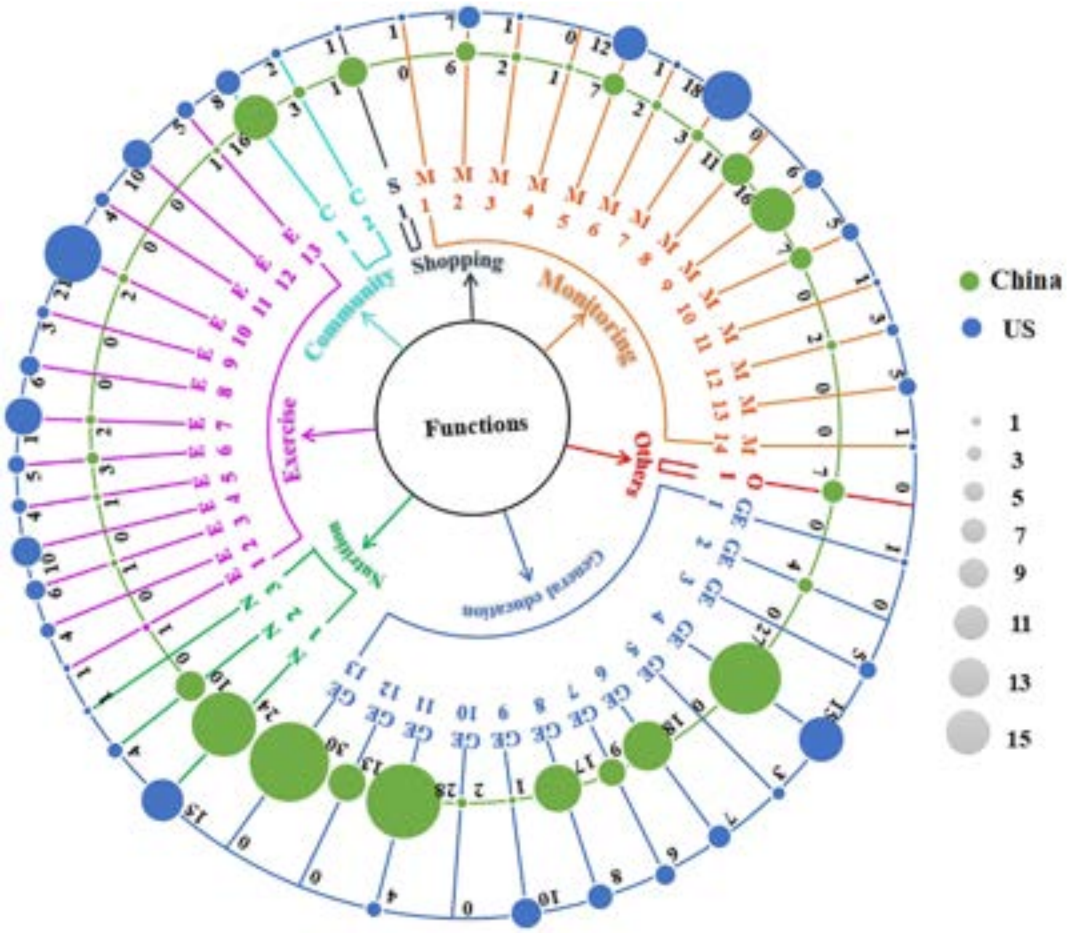

FIGURE 3
The bubble chart compares the secondary models of 34 Chinese and 31 United States-based mobile apps for prenatal to postnatal nutrition and physical activity. Abbreviations used in this figure are detailed in Figure 2.

data have severely harmed consumers' legitimate rights and interests (42). We recommend that consumers refrain from installing programs that display excessive permission-seeking or lack privacy declarations and that government authorities increase internet monitoring. More importantly, more than half of the Chinese and US apps did not include citations or identify their scientific authority for the content they provided. The mean score for information quality was the lowest of all the MARS sub-scores in both China and the United States. Given the benefits of mHealth apps for maternal health and the fact that this population may be more susceptible to misleading information (43, 44), it is critical that they provide accurate, comprehensive, and trustworthy N&PA information throughout the pre- and postpartum periods. This may be a challenge for developers because they may lack relevant knowledge, so a multidisciplinary professional development team may be a requirement to ensure the quality of the app in the future.

Almost three-quarters (71%) of US apps contained in-app purchasing; this may be due to US apps including a plethora of fitness-related pregnancy training and postpartum recovery courses (Table 1). In comparison to pregnancy in China, pregnancy in Western countries tends toward fewer taboos and more physical activity (40, 45), which may explain the significant in-app purchase discrepancy between apps in the two nations. High-quality, convenient online prenatal fitness sessions can benefit maternal and fetal health (46). Including a fitness component in Chinese maternity apps is important, especially considering the current COVID-19 pandemic. Furthermore, there were significant linguistic discrepancies between the US and Chinese apps. An app is available in a virtual store; therefore, the user would likely have to select one in their own language. In addition, having a multi-language system is unnecessary because popular apps used by individuals in other nations sometimes have specialized overseas versions in China.

The quality of an app impacts not only the number of active users but also the capital growth of the firm that created

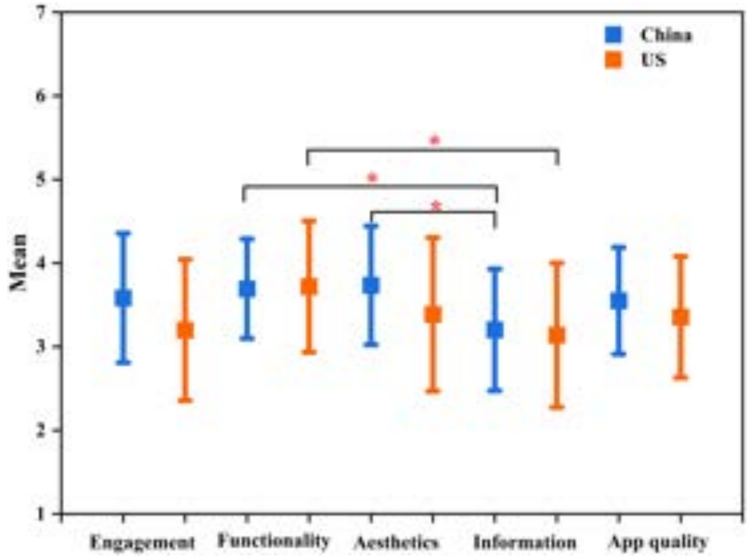

FIGURE 4
Mean difference in the engagement, functionality, esthetics, information, and overall app quality scores between included apps from the United States and China. *$p < 0.05$.

it (35). User feedback (subjective quality) is a way for new users to immediately assess an app's quality, and research has shown it to be highly influential in convincing new users to download an app (29). The quality of an app comprises user engagement, information, functionality, and esthetics (25). Both countries showed satisfactory levels of subjective and app quality, with China slightly surpassing the United States in both aspects (Figure 4). N&PA app development in the future should be enhanced from an acceptable quality level to one that is convenient, reliable, and high quality that meets the needs of target consumers. The Pearson correlation analysis revealed no association between user rating and app quality (Figure 5); therefore, our hypothesis predicting a link between app quality and user rating was not supported by the above finding. We suggest that user ratings should not be utilized as a stand-alone element to determine the quality of an app and whether to install it as a user.

4.1.2. Functionalities and modules

According to our findings, the most frequently included modules set by developers in prenatal N&PA apps in China and US were monitoring, general education, nutrition, exercise, community, and purchasing (Figure 2).

General education characteristics varied substantially between China and the United States (Figure 3). Pregnancy diet and exercise taboo knowledge were more prevalent in Chinese apps, while nutrition knowledge for women TTC and pregnancy with type 2 diabetes were more prevalent in US apps (Figure 3). This distinction may be due to the cultural differences between Chinese and Western pregnancy, as discussed above (40). In addition, the pregnancy guidelines developed in recent years by the United States and European nations, which include nutrition and exercise recommendations as well as information on prenatal examination, obesity, and other pregnancy complications at all stages of pregnancy may contribute to these differences (47, 48). When pregnant women acquire nutritional knowledge, they are better prepared to avoid common nutritional errors, create healthy eating habits, and manage their weight during pregnancy (49). This implies that app-based general education in the United States and China should include complete information for the entire PtP period, as it would be beneficial to maternal and fetal health.

Compared to Chinese apps, US apps included more exercise-related content (i.e., pregnancy yoga, fitness, and meditation) (Figure 3). The possible reasons for this difference in pre- and postpartum exercise modules have been previously addressed. Despite evidence demonstrating the advantages of exercise during pregnancy, many pregnant women do not engage in the recommended amount of physical activity due to a lack of financial resources or expert support, in addition to isolation during the COVID-19 pandemic (15, 16). Because online courses are more affordable than those provided by professional organizations, we recommend that Chinese apps be improved to address this issue of accessibility by including exercise modules. This would ensure that users can access beneficial exercise modules, even in impoverished areas and during COVID-19-related isolation.

Nutrition modules mainly consisted of recipe suggestions (i.e., three meals a day, dessert, and snacks), cooking methods, nutritional components, and calories in food (Figure 2). In

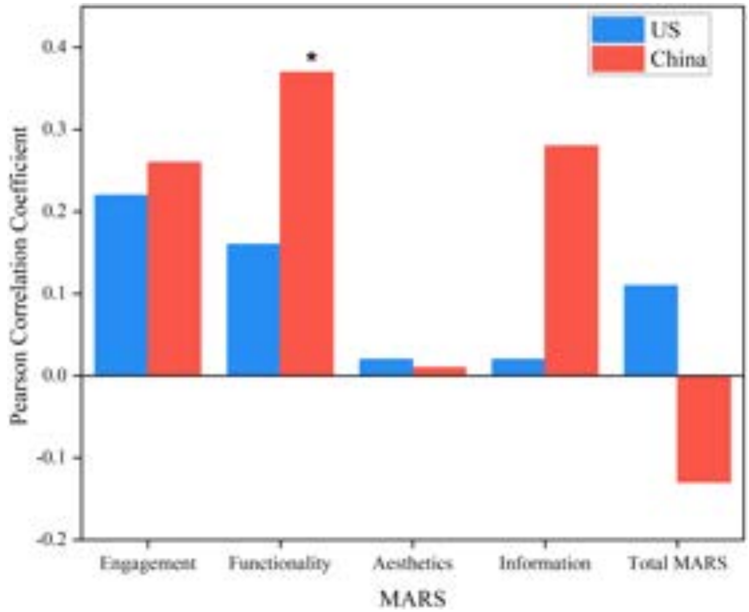

FIGURE 5
The bar chart illustrates the Pearson coefficients between Chinese and United States mobile app quality rating, four dimensions rating of app quality, and user rating. The Pearson coefficients' maximum positive and negative limits are indicated above and below the origin line at zero. *$p < 0.05$.

the Chinese apps, recipe guidance that included cooking steps, calories, and nutrition facts was more common than in the US apps. Given that Chinese food involves more intricate processes and ingredients than Western cuisine, detailed guidance may be necessary to match consumer expectations. Meanwhile, neither the Chinese nor the US apps offered any nutrition advice specific to before, during, or after exercise. According to the International Society of Sports Nutrition, proper nutritional intake before, during, and after exercise would significantly enhance exercise capacity and maintenance of normal physical function (50). We propose that app developers highlight the efficient combination of diet and exercise to promote maternal and fetal health.

4.2. Strengths and limitations

Several merits and limitations should be addressed in this research before evaluating the conclusions. We contribute to the literature in the following ways. First, apps from two nations with very different healthcare systems, cultures, and economic statuses were compared. This allowed us to evaluate app functionality and usage on a more global scale. Second, this research is the first to examine the link between user rating and app quality associated with in-store PtP N&PA apps in the United States and China. Third, we behaved as users at different PtP periods to gather data and ensure we did not miss critical information. Finally, the collected data were rigorously examined to verify that they were trustworthy and consistent prior to performing the analysis. There were also some limitations, as follows. First, we reviewed the apps at a single point in time, which means we may have ignored modifications to app functionality over the long term. Second, we also removed paid apps without free trials, which could have prevented us from accessing all the available information. Third, the possibility of evaluation bias should be acknowledged. Although app quality was independently assessed by six researchers and agreement was high, it is possible that ratings were subject to individual preference. Finally, a language barrier prevented us from including apps from other countries. Future investigators may seek to examine other time periods to produce longitudinal comparisons of functional modules and quality across a larger number of countries.

5. Conclusion

In summary, the basic characteristics and functional modules of in-store mobile PtP N&PA apps varied between the United States and China. Apps from both counties, but notably those from China, shared common deficits, including a lack of evidence-based information, the potential for misleading material, and the absence of empirical app assessments. Chinese apps had a higher concentration of educational content, while US apps had a higher concentration of workout-related information. The app quality of both countries was considered satisfactory, and there was no correlation between app quality and user rating. These results highlight the need to provide the reliable information of PtP N&PA apps present in both nations and suggest that user ratings cannot be used as an objective indicator of app quality. Effective regulation of app information is required to ensure the quality of in-store apps. Women's basic public health-related services may be promoted *via* the creation of highly effective PtP apps.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

HY: conceptualization, funding acquisition, software, validation, visualization, and writing of the original draft. HY, JH, KL, WQ, and JL: data curation and formal analysis. HY and JH: methodology. HY and AS: project administration, resources, supervision, and writing of the review and editing. All authors revised and approved the manuscript.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.942331/full#supplementary-material

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Effects of 8-Week Online, Supervised High-Intensity Interval Training on the Parameters Related to the Anaerobic Threshold, Body Weight, and Body Composition during Pregnancy: A Randomized Controlled Trial

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Abstract: We aimed to assess the effects of an 8-week, online high-intensity interval training (HIIT) program on the parameters related to the anaerobic threshold (AT), body weight, and body composition in pregnant women. A total of 69 Caucasian women with an uncomplicated singleton pregnancy (age: 31 ± 4 years; gestational age: 22 ± 5 weeks; mean ± standard deviation) were randomly allocated to either an 8-week HIIT program (HIIT group) or to a comparative 8-week educational program (EDU group). Our most important finding was that even with the 8-week progression of pregnancy and physiological weight gain, the HIIT group maintained the same level of parameters related to AT: volume of oxygen at the AT (VO_2/AT), percentage of maximal oxygen uptake at the AT (%VO_{2max}/AT), and heart rate at the AT (HR/AT). In contrast, in the EDU group we observed a substantial deterioration of parameters related to the AT. The HIIT intervention substantially reduced the fat mass percentage (median: 30 to 28%; $p < 0.01$) and improved the total fat-free mass percentage (median: 70% to 72%; $p < 0.01$). In the EDU group, the body composition did not change significantly. An online, supervised HIIT program may be used to prevent the pregnancy-related risk of excessive weight gain and reduction in exercise capacity without yielding adverse obstetric or neonatal outcomes.

Keywords: pregnancy; high-intensity interval training; body composition; anaerobic exercise capacity; anaerobic threshold

1. Introduction

The National Center for Health Statistics indicated that maternal mortality has increased by 33% in the second trimester and 41% in the third trimester since the onset of the COVID-19 pandemic [1]. These changes may be attributed to conditions directly related to COVID-19 such as respiratory infections or conditions aggravated by viruses such as hypertension, diabetes, and cardiovascular disease [1].

Obesity in pregnancy is associated with many comorbidities and disorders, including a higher rate of COVID-19 infection and its complications [2]. In addition, obesity significantly reduces the maximal sustained exercise capacity with an earlier reach of the anaerobic threshold (AT) [3]. The AT refers to the moment of metabolism shift during exercise when the oxygen consumption above which aerobic energy production is supplemented by anaerobic mechanisms causes a sustained increase in lactate and metabolic acidosis [4]. This index has been associated with exercise capacity, cardiorespiratory fitness, and surgery risk, making it a useful parameter for the development, implementation, and evaluation of exercise programs [5].

Maternal body composition undergoes profound adaptive changes during pregnancy. Both fat mass and lean body mass grow differently, and excessive weight gain is relatively prevalent. The percentage of fat mass (%FM) was strongly associated with gestational diabetes risk and markers of cardiovascular health in pregnancy [6]. Exercise has beneficial effects on the AT and thereby in patients with obesity, hypertension, diabetes and cardiovascular disease [7–11]. However, many expectant mothers avoid or considerably reduce their usual exercise routine due to the fear of potential risks [12]. According to the current evidence-based guidelines [13,14], there are no known risks associated with moderate-intensity exercise in women with uncomplicated pregnancies. Furthermore, vigorous exercise during pregnancy among women who are well trained prior to conception has no negative effects on the procession of pregnancy, labor, or the unborn child [15]. Aerobic exercise can improve aerobic fitness in pregnant women, promote fat burning, and delay elevations in blood lactate levels during graded exercise testing [7,16,17].

Sports fitness training, particularly high-intensity interval training (HIIT; brief bouts of vigorous exercise interspersed with intervals of rest or active recovery), has recently attracted the attention of researchers [18]. HIIT has been demonstrated to not only improve cardiovascular function but also significantly increase mitochondrial activity in the skeletal muscle, glucose and lipid metabolism, and overall body composition [19].

A minimum of 150 min per week of moderate-to-vigorous exercise during pregnancy is safe and recommended in the absence of obstetric or medical complications or contraindications by credible gynecology, obstetrics, and sports medicine institutes, including the World Health Organization [20–23]. Yoga and slow walking are common during pregnancy but require a considerable time commitment and training duration to be effective [12]. As a time-efficient alternative, HIIT has evolved into a training approach with the potential to burn fat and enhance the AT in both healthy individuals and patients, including those with cardiovascular disease [24], cancer [25], or obesity [26]. Notably, most studies have involved older adults, women who have already undergone menopause, and pregnant elite athletes. There are limited data on the effectiveness of HIIT in inducing weight loss, body composition, and AT changes in pregnant women who are non-athletes and were inactive before pregnancy [14].

To address the aforementioned concerns, this study aimed to: (1) evaluate the effects of an 8-week HIIT program on selected parameters related to the anaerobic threshold and body composition during pregnancy; and (2) examine the relationship between the characteristics of the exercise intervention and changes in the selected parameters related to the anaerobic threshold and body composition.

2. Materials and Methods

2.1. Ethics, Recruitment, and Flow of the Participants through the Study

This study was conducted at the Laboratory of Physical Effort and Genetics in Sport at the Gdansk University of Physical Education and Sport in Poland in 2021. All procedures were performed in accordance with the principles outlined in the Declaration of Helsinki of the World Medical Association (WMA) and approved by the Bioethics Commission of the District Medical Chamber in Gdansk (KB-8/21). The entire research protocol was registered with ClinicalTrials.gov (NCT05009433) on 17/08/2021 and was entitled "HIIT vs. MICT During Pregnancy and Health and Birth Outcomes in Mothers and Children (HIIT Mama)". After the trial began, no marked methodological adjustments were made. The study adhered to the principles of openness, transparency, reproducibility, and the CONSORT standards [27].

This randomized controlled trial was conducted on 69 Caucasian women with uncomplicated singleton pregnancies ([mean ± standard deviation] age: 31 ± 4 years, gestational age: 22 ± 5 weeks) who consented to participate in the study after receiving our mass media invitation.

The eligibility criteria for both groups were as follows: (1) correct course of gestation confirmed during the standard obstetric examination for each pregnant woman in accordance with national law; (2) week of gestation not higher than 28 in order to be able to attend the entire intervention; (3) proficiency in the Polish language; and (4) any age. The exclusion criteria were as follows: (1) contraindications to increased physical exertion or other situations that could adversely affect the health or safety of the participants or the quality of the gathered data; (2) multiple pregnancy; (3) daily alcohol consumption; (4) lack of a tablet or computer with Internet access. Following a thorough explanation of all procedures and the potential risks involved, all participants signed an informed consent form before starting the baseline tests and interventions. All participants continued to receive routine obstetric care throughout the trial. Additionally, we asked them to comply with the recommendations for a healthy diet for pregnant women during the study.

At baseline, there were 35 pregnant women randomly allocated in the high-intensity interval training group (HIIT group). One participant attended only 3 classes and resigned from the intervention due to family commitments. Five participants from the HIIT group were excluded from analysis, because they attended less than 70% of the HIIT sessions planned for the 8-week exercise program (even though they underwent the post-intervention assessments). The reasons for their absence from the HIIT sessions were: busy with study or work (n = 2); busy with taking care of an older child (n = 2); or had an infection (n = 1). Additionally, we excluded from the analysis one participant who did not exercise with the recommended intensity during the HIIT sessions. It must be underlined that none of the HIIT participants were absent due to exercise-related health issues or because they considered the HIIT sessions too intensive for them.

We invited 34 pregnant women to the comparative group, which participated in the 8-week educational program (EDU group). Eleven women did not complete the intervention (i.e., they did not undergo the post-intervention assessments) due to the following reasons: not interested in continuing the program (n = 4); preterm birth (n = 1); had to take medications that could influence the study outcome (n = 1); not feeling well on the day of the second assessment (n = 2); or a lack of support from the obstetric care providers to continue the program (n = 2). One woman did not provide a reason (n = 1).

Finally, 49 pregnant women were included into the analysis: 28 from the HIIT group and 21 from the EDU group. The flowchart of participant flow through the study is illustrated in Figure 1.

As part of the characteristics of the study participants at the recruitment stage, we collected their demographic data and measured the level of physical activity using the short form of the International Physical Activity Questionnaire [28]. This questionnaire, which has shown acceptable measurement properties, provides information on weekly physical activity (PA) levels in multiples of the resting metabolic rate (MET). Based on the IPAQ outcomes, we categorized the pregnant participants using three levels (categories) of PA: low (inactive participants), moderate (accumulating a minimum recommended level of PA), and high (exceeding the minimum recommended level of PA) [29,30].

2.2. Cardiopulmonary Exercise Test

The cardiopulmonary exercise test (CPET) was conducted according to recommendations by the American Thoracic Society/American College of Chest Physicians using a cycle ergometer with an electronically regulated load (Viasprint 150P; Bitz, Germany) and a pulmonary gas analyzer (Oxycon Pro; Erich Jaeger GmbH, Hoechberg, Germany) [31]. All tests were calibrated according to the manufacturer's instructions. A data point for every 15 s period was calculated by averaging the breath-by-breath data. The women sat on a chair for 5 min with a silicon face mask for breathing adaptation before the actual test. After the adaptation period, the women began to warm up by cycling for 4 min with a relative load of 0.4 $W \cdot kg^{-1}$ of body mass. When the participants had warmed up, the load was increased by 0.2 $W \cdot kg^{-1}$ per minute until they refused. In preparation for the test, the women were encouraged to cycle up to the limit of their physical capacity. They were also informed that they could stop the test at any time. The participants rested for 3 min after they finished cycling. We used the same CPET protocol before and after the 8-week exercise program. At these two timepoints the number of applied Watts was related to individual participant's body weight (after 8 weeks the number of Watts was adjusted to the increased body weight).

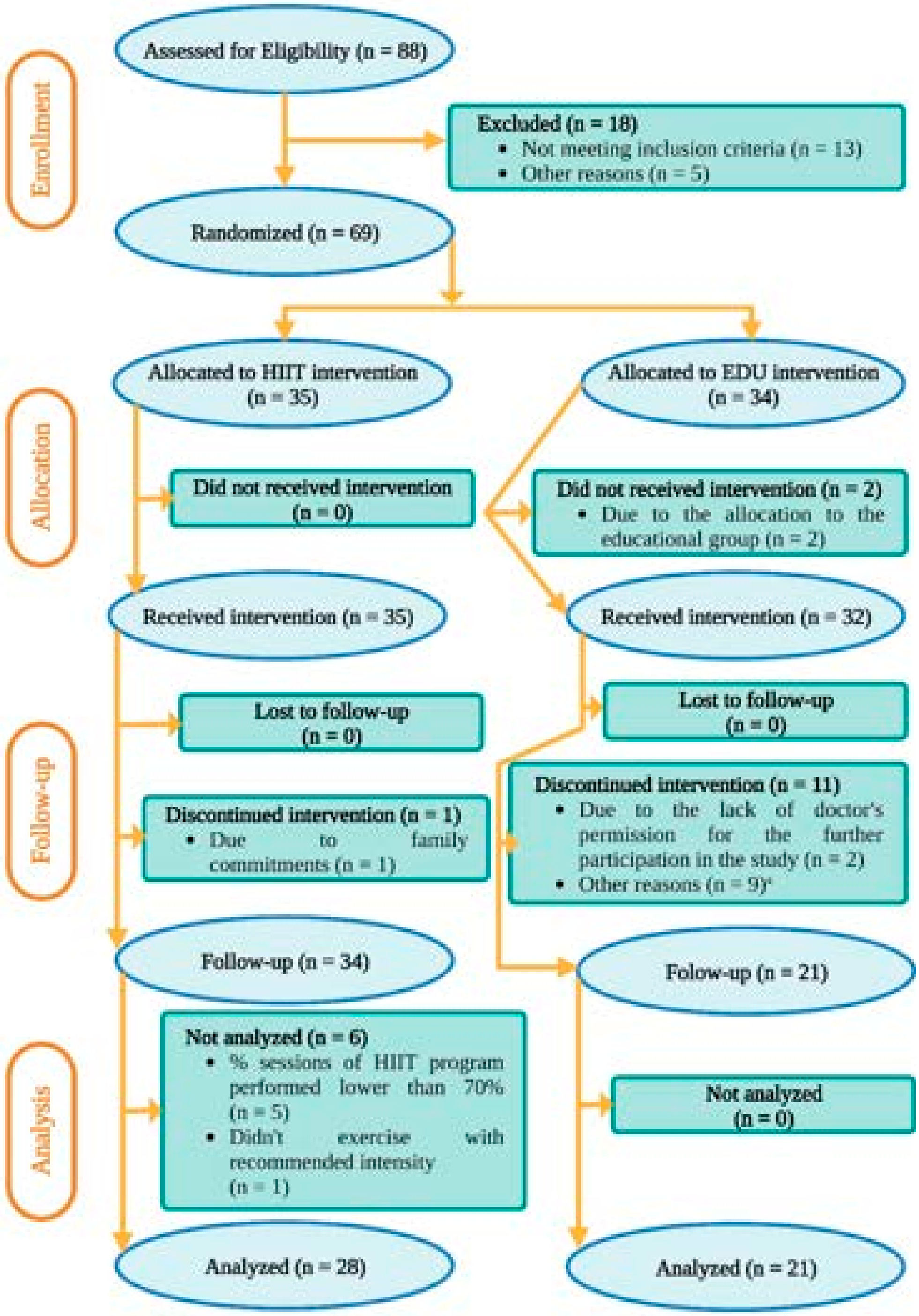

Figure 1. Flowchart of participant selection. EDU: education, HIIT: high-intensity interval training. [a] Not interested in continuing the program (*n* = 4); preterm birth (*n* = 1); taking medications that could influence the glucose level or lipid metabolism (*n* = 1); not feeling well on the day of the second assessment (*n* = 2); or did not provide a reason (*n* = 1).

The maximal oxygen uptake (VO_{2max}) was defined as the volume of oxygen consumed at maximal exertion sustained for 15 s. The AT was determined by utilizing a modified V-slope method and the ventilatory equivalent (VE) method [32]. The aerobic threshold (AerT) was determined by plotting the VE as a function of oxygen consumption (VE/VO_2). The volume of oxygen (VO_2) at which the lowest VE/VO_2 values were observed was defined as the AerT [33–35]. We set an individual heart rate at the aerobic threshold (HR/AerT) for each participant.

To determine the changes in the parameters related to the anaerobic thresholds of the participants, we analyzed the following parameters: volume of oxygen at the anaerobic threshold (VO_2/AT), heart rate at the anaerobic threshold (HR/AT), percentage of maximal oxygen uptake at the anaerobic threshold (%VO_{2max}/AT), time between the HR/AerT and HR/AT (time during the CPET from the moment when the aerobic capacity was fully used to the threshold when anaerobic exercise started to dominate), and time above the HR/AT (time from the moment when anaerobic exercise started to dominate up to exhaustion and termination of the test).

It should be pointed that cycle ergometer exercise tests are usually associated with significantly lower values of cardiopulmonary parameters (including HR_{max} and HR/AT) compared to treadmill exercise tests [36]. However, due to the higher risk of falling and higher load on the pelvic floor muscles during the maximal test performed by walking or jogging on the treadmill, we decided to use the cycle ergometer test. The data on selected parameters related to AT were collected in the same conditions before and after the 8-week interventions. Therefore, the analysis of changes in these parameters was trustworthy. We are aware that due to the above-mentioned characteristics of the exercise tests, the HR values given to the participants as HR/AT could be underestimated. Nevertheless, these values were set using the same methodology, which provided the same level of underestimation (if any) for all participants.

2.3. Body Composition

We measured the participants' body mass and composition via bioelectrical impedance analysis using InBody 720 (InBody USA, Cerritos, CA, USA). The body mass index (BMI) was calculated as follows: weight in kilograms/height in meters squared. The reliability of InBody 720 was previously proven by McLester et al. [37]. Before and after the HIIT and EDU interventions, we utilized the standard InBody 720 to record and analyze the total fat mass percentage (%FM) and total fat-free mass percentage (%FFM).

2.4. High-Intensity Interval Training

Our preparation for the HIIT intervention used in this trial was preceded by a thorough analysis of the current guidelines for exercise during pregnancy published by credible obstetrics, gynecology, or sports medicine institutions [13]; an analysis of recommendations on prenatal exercise program design and implementation [13,38]; and a review of available data on HIIT during pregnancy [14].

The HIIT intervention consisted of three training sessions per week for 8 weeks with each session lasting 60 min. Seven to ten minutes were spent on a warm-up and instruction on how to perform the main exercises. The main part of the session consisted of a high-intensity interval exercise, which lasted 15–20 min (Figure 2). The HR/AT was calculated for each participant using a progressive maximal exercise test and set at 87 $\pm$ 5% of the maximal heart rate on average. The participants were instructed to use a heart rate monitor (Polar RS400, Kempele, Finland) and train at intensities that exceeded the HR/AT for as long as they felt comfortable during the workout interval. We assumed that some of them would not be able to exercise above the AT in all workout intervals, inter alia due to the fear of endangering the baby or feelings of tiredness. However, even though they spent more time below the AT (only trying to reach this level) during the sessions, we can define our intervention as HIIT. According to the definition by Wood et al., HIIT protocols should be based on short work intervals (<60 s–8 min) of vigorous (70–90% maximal heart rate or 14–16 of the 6–20 Borg's rate of perceived exertion—RPE) to high intensity (≥90% maximal heart rate or ≥17 of the 6–20 RPE) interspersed with active (40–70% maximal heart rate or 8–13 of the 6–20 RPE) or passive (cessation of movement) recovery periods (of 1–5 min) [39]. The individual HR values from all sessions were recorded and analyzed after the completion of the intervention.

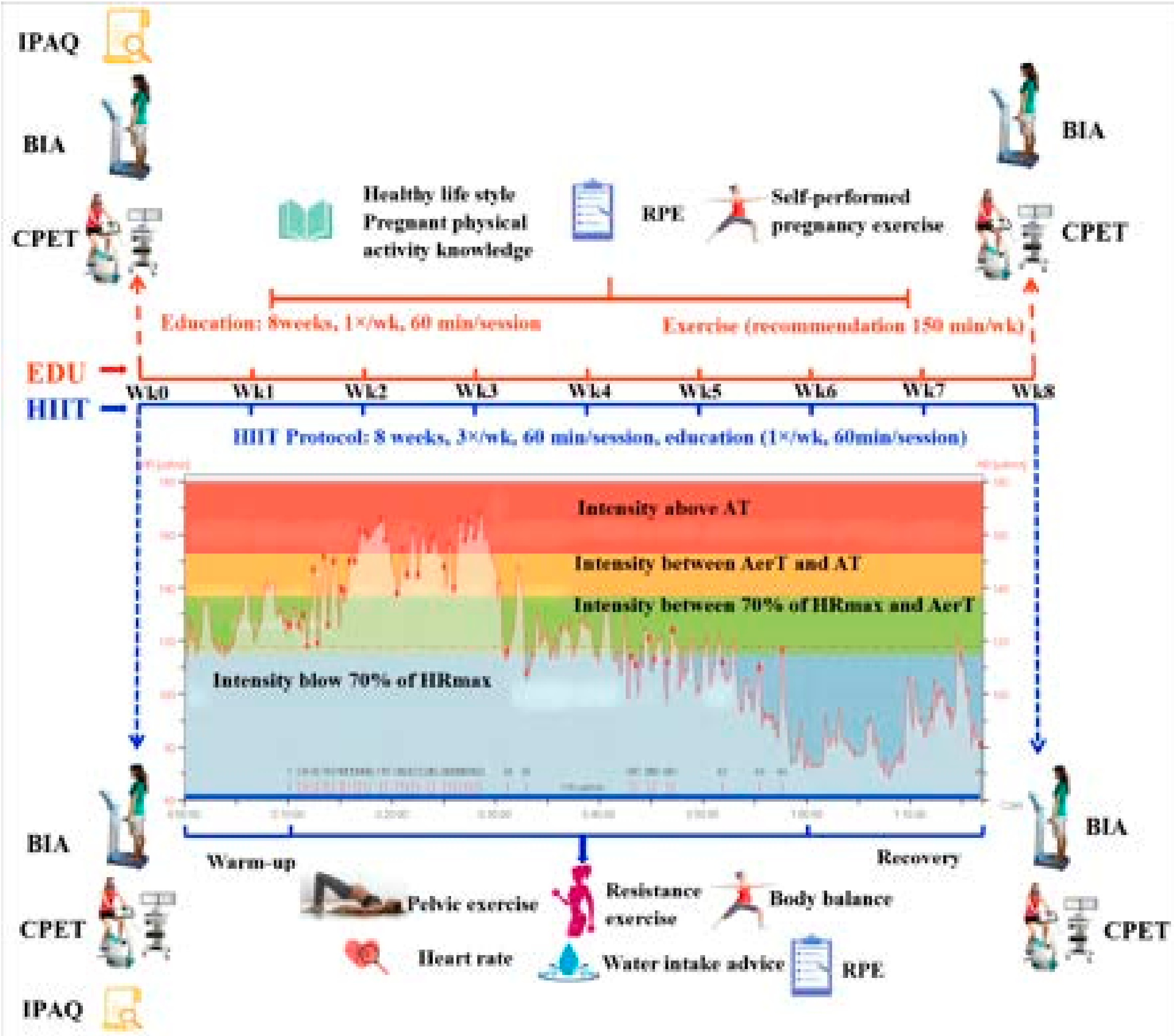

Figure 2. Schematic representation of the study protocol. AerT: aerobic threshold, AT: anaerobic threshold, BIA: bioelectrical impedance analysis, CPET: cardiopulmonary exercise test, EDU: education, HIIT: high-intensity interval training, HR_{max}: maximal heart rate, IPAQ: International Physical Activity Questionnaire, RPE: rating of perceived exertion.

Additionally, the 0–10 Borg Rating of Perceived Exertion (RPE) Scale [40] and the Talk Test [41] were used to assess the exercise intensity. In order to monitor the participants' well-being and their acute response to exercise, we asked them to complete individual Exercise Monitoring Cards after each exercise session. The Exercise Monitoring Cards contained the following information: date of exercise session, form of physical activity (participants were asked to enter all forms of physical activity also individually taken; e.g., walking, cycling), the duration of exercise, subjective assessment of exercise intensity at 0–10 RPE scale, rest time after exercise, well-being during or after exercise on day of classes, any comments, and the reason for absence (applicable to HIIT sessions) [13].

The workout intervals included exercises that targeted the major muscle groups (e.g., lunges, squats, jumps, or combinations with upper body movements). The ratio of exercise to rest was set at 1:2, 1:1, or 2:1 depending on the ability of the participant, stage of pregnancy, and progression of training. The duration of each exercise ranged from 30 to 60 s with an equal-length rest break interval. We present the proportions of workout and rest intervals in the Table 1. After the interval portion of training, the participants performed 5–10 min of resistance, neuromotor (i.e., body balance), postural, and stretching exercises. The cool-down consisted of birth preparation and pelvic floor muscle exercises (i.e., birth position and breathing exercises; 5–10 min) along with relaxation and visualization of pregnancy and labor (5–15 min) (Figure 2). There was no workout equipment and the only resistance came from the participants' body weight. This exercise program was tailored to the requirements and capacities of the pregnant women based on diagnostic exercise test results. It was offered to the pregnant women regardless of their fitness level, athletic ability, or motor skills [13].

Table 1. The characteristics of HIIT intervention.

The Characteristics of HIIT Intervention					
Week Number	**Time of Workout Interval (s)**	**Time of Rest Interval (s)**	**Number of Sets (Workout + Rest Intervals)**	**Time between Sets (s)**	**Number of Cycles (Exercises)**
Week 1	30	60	4	60	4
Week 2	30	60	4	30	4
Week 3	45	45	4	60	4
Week 4	45	45	4	45	4
Week 5	45	45	4	30	4
Week 6	30	30	4	60	4
Week 7	30	30	4	30	4
Week 8	30	15	4	30	4

The HIIT sessions were held online through MS Teams from 9:30 a.m. to 10:30 a.m. on Mondays, Wednesdays, and Fridays except for one Monday that was a holiday (23 sessions in total). Even though we communicated with the participants through the Internet, all session were supervised in real time. We monitored the participants' well-being and exercise performance, corrected their technical mistakes, and asked for feedback. Therefore, for our intervention we used the term "online, supervised exercise program". On average, the participants attended 18 ± 5 sessions, which accounted for 78% of the entire training program. The HIIT group was allowed to perform additional exercise sessions as desired. The average number of additional sessions was 12 (median) with a range (min–max) of 0 to 39, while the average intensity was 5 (median) with a range (min–max) of 0 to 7 on the Borg RPE Scale. Before the program, the women were guided through the use of MS Teams to attend the online sessions and the safety precautions for exercising at home, which included the safe arrangement of space at home and communication guidelines in the case of an accident or worsening in health. The HIIT intervention was combined with an educational lesson once a week. The sessions were conducted by the primary researcher, who is a qualified as a Pregnancy and Postnatal Exercise Specialist according to the European educational standards [42] and is additionally educated in terms of online coaching in accordance with the European Lifelong Learning Qualification "Online Provision of Fitness Services" [43]. We utilized email and phone communication to maintain program adherence.

The educational intervention focused on a healthy lifestyle, physical exercise throughout the perinatal period, and specific issues in pregnancy and parenthood. It followed the same structure as the HIIT intervention (Figure 2). Online, synchronous educational classes were held once each week for a total of 8 weeks. We encouraged the EDU group to engage in physical activity on their own and attain at least the minimum level of physical activity recommended (a minimum of 150 min per week of moderate-to-vigorous intensity physical activity) (Figure 2). The group was asked to record a log of all their physical activity including daily activities (i.e., cleaning the house, shopping, or gardening) that lasted at least 10 min and any structured exercise sessions. The Talk Test and Borg RPE

Scale were employed to measure exercise intensity instead of heart rate monitoring. We suggested a level of exercise intensity at which they had a noticeable increase in breathing frequency. The women reported an average of 20 (median) bouts of physical activity with a mean intensity of 5 (median) on the Borg RPE Scale. The EDU group was also asked to complete the individual Exercise Monitoring Cards after each session.

Two months after delivery, we asked all participants about their childbirth outcomes using the same online questionnaire as in our previous study [44]. We collected data that included, among others, the gestational age at birth, type of delivery (nonoperational vaginal delivery, operational gestational delivery, or cesarean section), labor induction, labor augmentation, perineal lacerations, anesthetics used, and newborn's weight at birth and APGAR scores.

2.5. Statistical Analysis

The total sample size was predetermined via a priori and sensitivity analyses using G*×Power version 3.1.3. We expressed most data as means ± SDs and tested the normality of the data using the Shapiro–Wilk test. We presented non-normally distributed data as medians and ranges. The chi-square test was used to compare the non-parametric demographic characteristics between the EDU and HIIT groups. We used one-way ANOVA to compare the changes between the groups after interventions, and the value of Cohen's f was used to represent effect size (effect size conventions: small, f = 0.1; medium, f = 0.25; large, f = 0.4). Paired Wilcoxon tests were used to evaluate the changes before and after the HIIT intervention if data were not normally distributed (i.e., VO_2/AT and time above the HR/AT), and the value of Cohen's d was used to represent effect size (effect size conventions: small, d = 0.2; medium, d = 0.5; large, d = 0.8). We used Spearman's correlation coefficients to analyze the association of the changes in parameters related to AT and the changes in the body composition with the characteristics of the interventions. The significance level was set at $p \leq 0.05$. We performed all statistical analyses using OriginPro 2021 (version 9.8.0.200, OriginLab).

3. Results

A total of 49 participants were included for analysis (n = 28 in the HIIT group, n = 21 in the EDU group). Apart from parity ($p < 0.05$, Cohen's f = 0.36), none of the baseline demographic variables significantly differed between the groups (Figure 3). The participants in the HIIT and EDU group were in their 20 ± 4 and 23 ± 5 weeks of gestation, respectively. The difference was not statistically significant (p = 0.12). It also did not have clinical significance. The development of pregnancy proceeds at an individualized pace and its physiological termination is considered to be the time between the 38th and 42nd week of gestation. Therefore, the group of pregnant women with a difference of 3 gestational weeks can be considered homogeneous in this respect.

3.1. Parameters Related to the Anaerobic Threshold

The baseline parameters related to the AT did not significantly differ between the HIIT and EDU groups (Table 2). After 8 weeks, the values of VO_2/AT were significantly higher in the HIIT group than in the EDU group (HIIT group: 20.15 ± 3.47 mL·kg^{-1}·min^{-1} vs. EDU group: 15.67 ± 2.89 mL·kg^{-1}·min^{-1}, $p < 0.01$, Cohen's f = 0.73; Figure 4a). Similarly, the values of HR/AT were significantly higher in the HIIT group than in the EDU group after the interventions (HIIT group: 151 ± 10 beats·min^{-1} vs. EDU group: 143 ± 12 beats·min^{-1} vs., $p < 0.01$, Cohen's f = 0.48; Figure 4b).

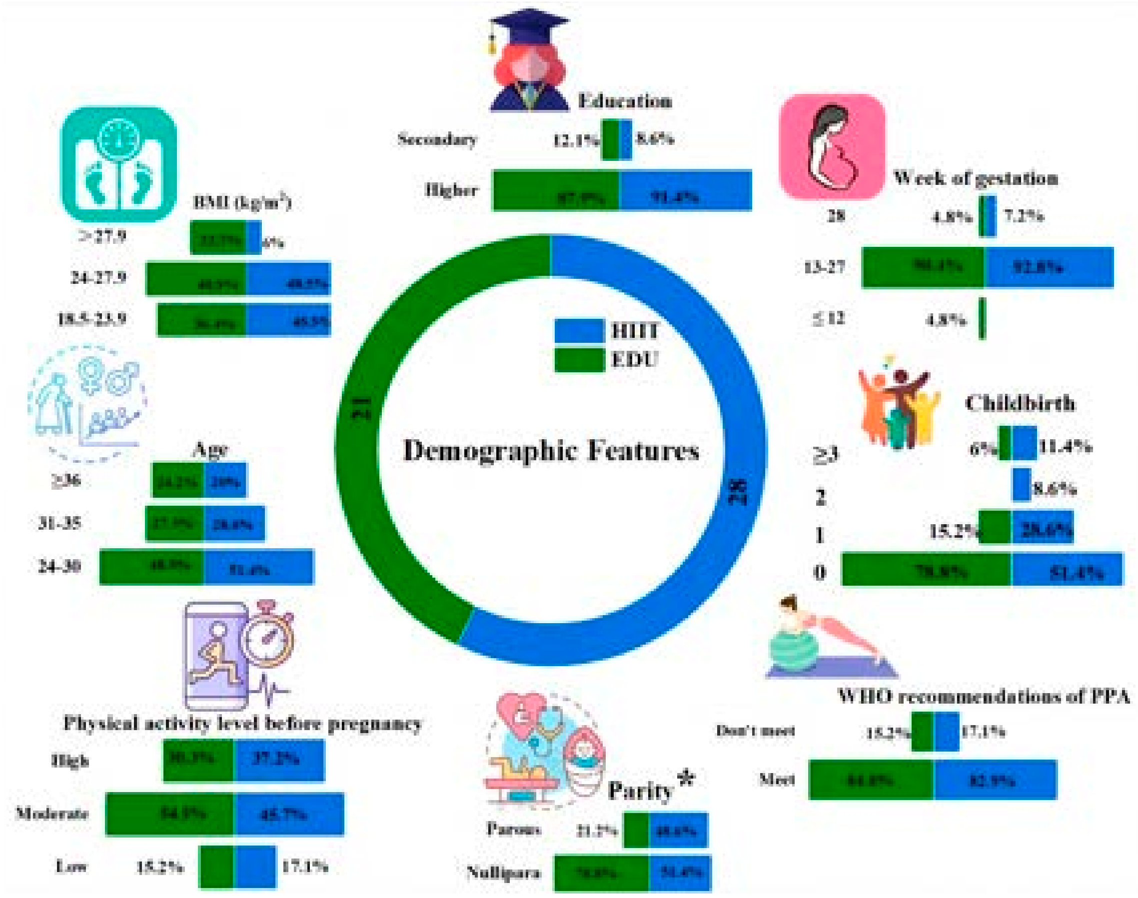

Figure 3. Comparison of the baseline demographic characteristics between the HIIT (n = 28) and EDU (n = 21) groups, BMI: body mass index, EDU: education, HIIT: high-intensity interval training. The analysis was conducted using the chi-square test (* $p < 0.05$).

Table 2. Comparison of the baseline parameters related to the anaerobic threshold between the HIIT and EDU groups.

Parameters Related to the Anaerobic Threshold at Baseline	Group (Mean ± SD [6])			
	EDU [2] (n = 21)	HIIT [3] (n = 28)	p	Cohen's f
HR/AT [1] (beat·min^{-1})	151 ± 10	153 ± 9	0.56	0.09
Time between the HR/AerT [4] and HR/AT [5] (s)	92.76 ± 24.19	79.48 ± 29.83	0.10	0.24
Time above the HR/AT (s)	140.74 ± 52.05	128.07 ± 47.83	0.38	0.13
VO_2/AT [7] (mL·kg^{-1}·min^{-1})	19.13 ± 2.86	20.38 ± 2.93	0.14	0.22
%VO_{2max}/AT [8] (%)	79.18 ± 7	78.96 ± 7	0.16	0.20

[1] AT: anaerobic threshold, [2] EDU: educational, [3] HIIT: high-intensity interval training, [4] HR/AerT: heart rate at the aerobic threshold, [5] HR/AT: heart rate at the anaerobic threshold, [6] SD: standard deviation, [7] VO_2/AT: maximal oxygen uptake at anaerobic threshold, [8] %VO_{2max}/AT: percentage of maximal oxygen uptake at the anaerobic threshold. Data were analyzed using one-way ANOVA.

We observed a further beneficial outcome of the HIIT intervention: the time between the HR/AerT and AT (pre- to post-intervention median: 76 to 92 s, z = 2.76, $p < 0.01$, Cohen's d = 0.43; Figure 4c) and the time above the HR/AT (pre- to post-intervention median: 117 to 160 s, z = 3.59, $p < 0.01$, Cohen's d = *0.83*; Figure 4d) were considerably improved in this group after 8 weeks. In contrast, in the EDU group we noticed worse values of some parameters related to the AT. The values of VO_2/AT and HR/AT significantly decreased in the EDU group (pre- to post-intervention median: 19.7 to 15.3 mL·kg^{-1}·min^{-1}, z = 3.92, $p < 0.01$, Cohen's d = 1.94 (Figure 4a); 150.5 to 140.5 beats·min^{-1}, z = 3.41, $p < 0.01$, Cohen's d = 1.39 (Figure 4b)).

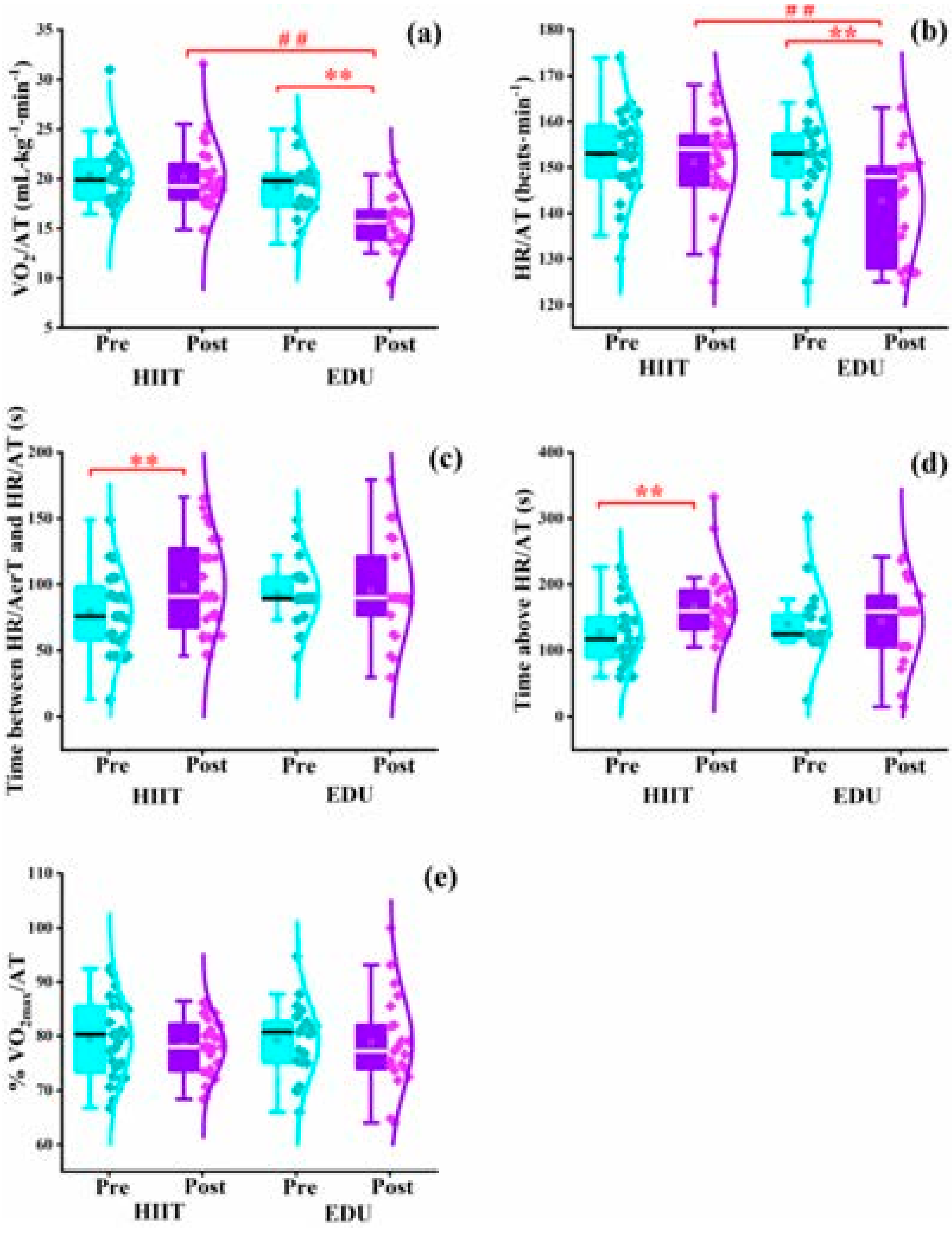

Figure 4. Box charts (**a**–**e**) showing the entire distribution of raw data (rhombus) and the median value (central line) of the parameters related to the anaerobic threshold before and after the 8-week HIIT (n = 28) and educational interventions (n = 21). EDU: education, HIIT: high-intensity interval training, HR/AerT: heart rate at the aerobic threshold, HR/AT: heart rate at the anaerobic threshold, VO_2/AT: maximal oxygen uptake at anaerobic threshold, %VO_{2max}/AT: percentage of maximal oxygen uptake at the anaerobic threshold. Data were analyzed using one-way ANOVA ($^{\#\#}$ $p < 0.01$) and a paired Wilcoxon test (** $p < 0.01$).

3.2. Body Composition

The baseline body composition did not significantly differ between the HIIT and EDU groups (Table 3). Interestingly, in the HIIT group the %FFM substantially increased after the 8-week intervention (from a median of 70% to 72%; z = 4.25, $p < 0.01$, Cohen's d = 1.05;

Figure 5c) and the %FM substantially decreased after 8 weeks of HIIT program (from a median of 30% to 28%; z = 4.25, $p < 0.01$, Cohen's $d = 1.05$; Figure 5b).

Table 3. Baseline body composition in the HIIT and EDU groups.

Body Composition	Group				*p*	Cohen's *f*
	EDU [2] ($n = 21$)		HIIT [3] ($n = 28$)			
	Median	Range (Min–Max)	Median	Range (Min–Max)		
BMI [1] ($kg \cdot m^{-2}$)	25.23	(22.4–27.5)	23.75	(22.4–26.9)	0.11	0.24
Weight (kg)	70.90	(65.1–78.3)	67.10	(61.8–72.0)	0.17	0.20
%FM [5]	32.9	(30–40)	30.3	(30–30)	0.14	0.22
%FFM [4]	67	(60–70)	70	(70–80)	0.14	0.22

[1] BMI: body mass index, [2] EDU: educational, [3] HIIT: high-intensity interval training, [4] %FFM: fat-free mass percentage, [5] %FM: fat mass percentage.

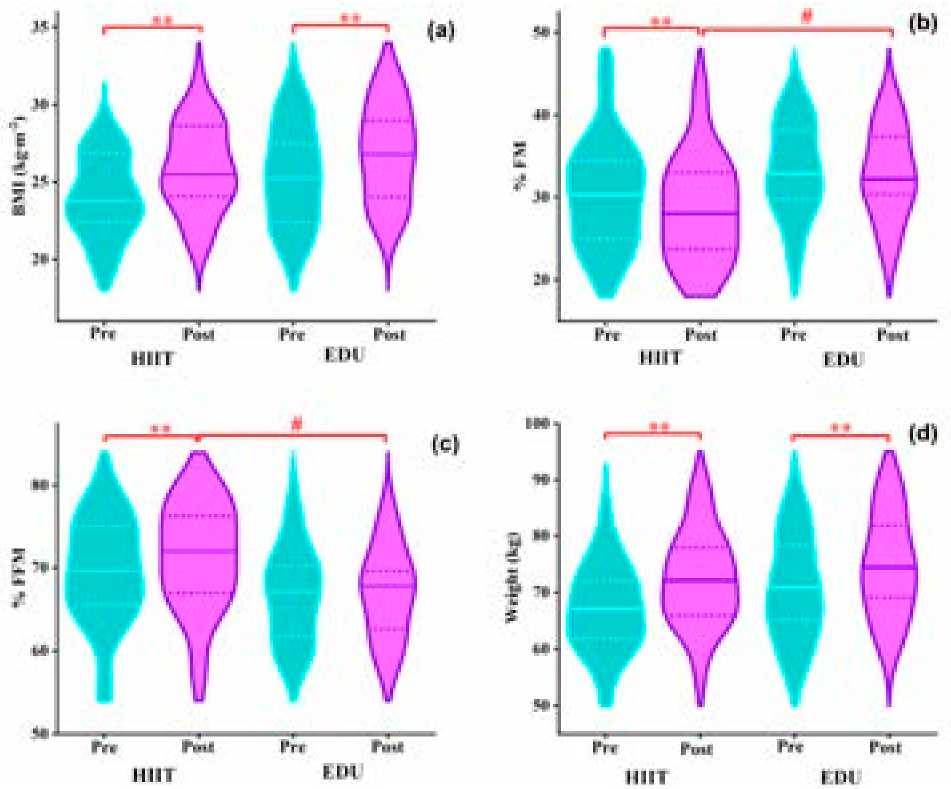

Figure 5. Violin plots (**a**–**d**) showing the entire distribution of the median (central line) and interquartile range (lower and upper lines) of the body composition before and after 8 weeks of the HIIT and educational interventions. BMI: body mass index, EDU: education, HIIT: high-intensity interval training, %FFM: fat-free mass percentage, %FM: fat mass percentage. Data were analyzed using one-way ANOVA ($^{\#}$ $p < 0.01$) and a paired Wilcoxon test (** $p < 0.01$).

What is more, after the interventions, in the HIIT group the %FM was significantly lower (respectively: 28% and 32%; $p < 0.05$, Cohen's $f = 0.34$; Figure 5b) and the post-intervention %FFM was higher than in the EDU group (respectively: 72% vs. 68%; $p < 0.05$, Cohen's $f = 0.34$; Figure 5c).

As expected due to the progression of the pregnancies, the BMI and body weight were significantly increased in both groups after the 8-week interventions The outcomes for BMI were: in the HIIT group, from a median of 23.74 to a median of 25.48 $kg \cdot m^{-2}$, z = 4.70, $p < 0.01$, Cohen's $d = 3.73$; in the EDU group, from a median of 25.23 to 26.77 $kg \cdot m^{-2}$, z = 3.98, $p < 0.01$, Cohen's $d = 2.05$ (Figure 5a). The outcomes for body weight were: in the HIIT group, from a median of 67.1 to 72.1 kg, z = 4.70, $p < 0.01$, Cohen's $d = 3.95$; and in the EDU group, from a median of 70.9 to 74.4 kg, z = 3.98, $p < 0.01$, Cohen's $d = 2.06$; (Figure 5d).

3.3. Relationship of the Body Composition and the Parameters Related to the Anaerobic Threshold with the Intervention Characteristics

The Spearman's correlation coefficients between the changes in the parameters related to the anaerobic threshold (%VO_{2max}/AT, HR/AT, time above the HR/AT, VO_2/AT, and time between the HR/AerT and HR/AT) and body composition (BMI, %FM, and %FFM) and the characteristics of the intervention (number of HIIT sessions, number of self-performed sessions, and RPE) in the HIIT and EDU groups are shown in Figure 6.

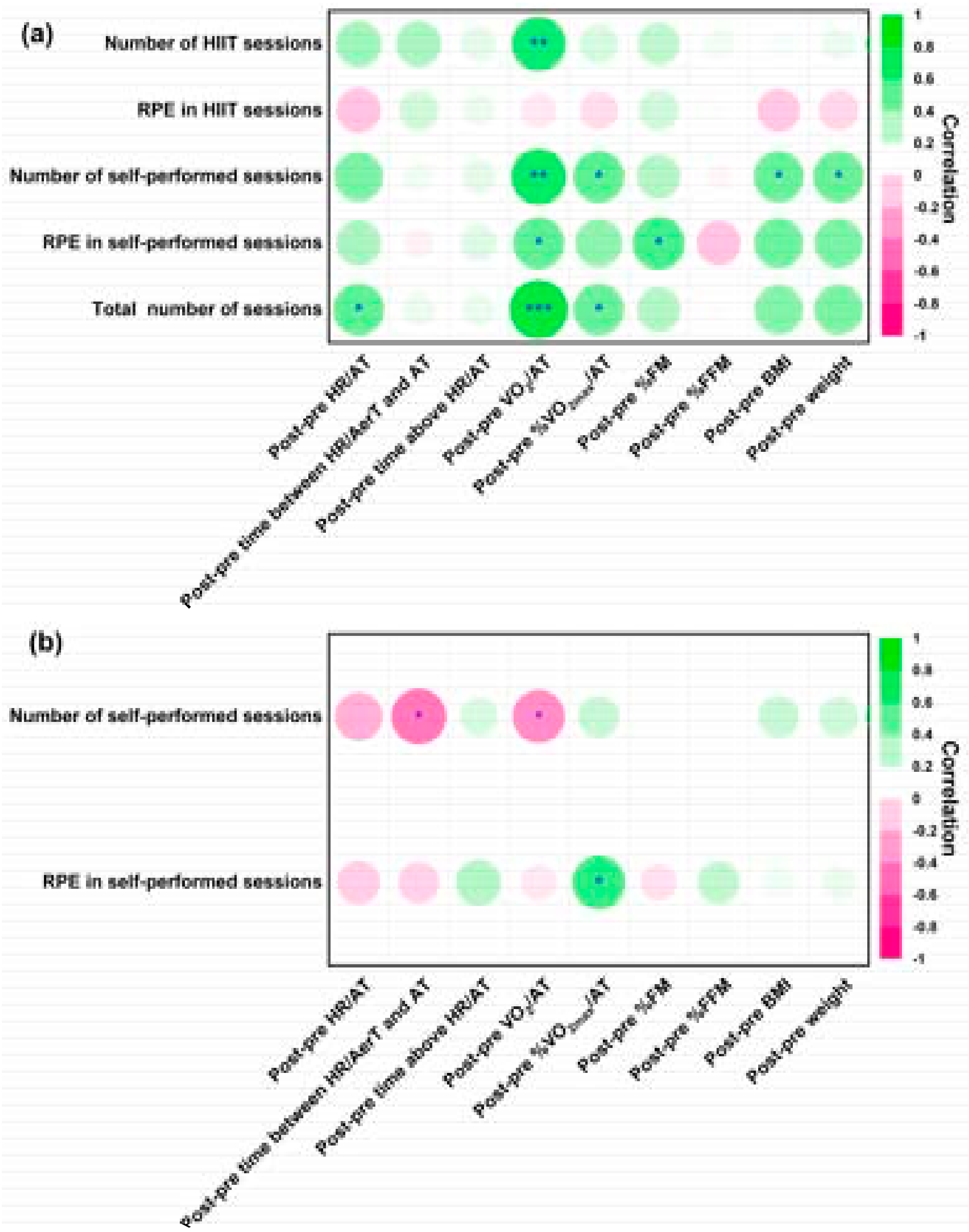

Figure 6. Heat maps of Spearman's correlation coefficients of the changes in the body composition and parameters related to the anaerobic threshold and intervention characteristics in the HIIT (**a**) and

EDU groups (**b**). AerT: aerobic threshold, BMI: body mass index, EDU: educational, HIIT: high-intensity interval training, HR/AerT: heart rate at the aerobic threshold, HR/AT: heart rate at the anaerobic threshold, RPE: rating of perceived exertion, VO_2/AT: maximal oxygen uptake at anaerobic threshold, %FFM: fat-free mass percentage, %FM: fat mass percentage, $\%VO_{2max}$/AT: percentage of maximal oxygen uptake at the anaerobic threshold. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. A darker color indicates a stronger correlation and vice versa; green shows a positive association, whereas red shows a negative association.

In the HIIT group, the number of HIIT sessions was positively correlated with the change in the VO_2/AT (r = 0.53, $p < 0.01$), and the number of self-performed sessions was positively associated with the changes in the VO_2/AT (r = 0.58, $p < 0.01$), $\%VO_{2max}$/AT (r = 0.40, $p < 0.05$), BMI (r = 0.38, $p < 0.05$), and weight (r = 0.40, $p < 0.05$). Interestingly, the higher the intensity of self-performed sessions as measured by RPE scale, the higher the increase in the values of VO_2/AT (r = 0.42, $p < 0.05$) and %FM (r = 0.46, $p < 0.05$). What is more, the more exercise sessions women performed in total, the more significant the changes in the VO_2/AT (r = 0.68, $p < 0.001$), HR/AT (r = 0.40, $p < 0.05$), and $\%VO_{2max}$/AT (r = 0.40, $p < 0.05$) were.

In the EDU group, the number of self-performed sessions was negatively correlated with the changes in the time between the HR/AerT and HR/AT (r = −0.53, $p < 0.05$) and VO_2/AT (r = −0.45, $p < 0.05$), while the RPE in the self-performed sessions was positively correlated with the $\%VO_{2max}$/AT (r = 0.47, $p < 0.05$).

Neither in the HIIT nor in the EDU group did we observe any adverse effects of our interventions on the development of pregnancy, childbirth, or neonatal outcomes The premature birth that was noted by one of the participants from the EDU group was not related to physical activity or any other lifestyle factors.

4. Discussion

In this study, we examined the effects of an 8-week online, supervised HIIT intervention on parameters related to the anaerobic threshold (AT) and body composition in pregnant women. One of our most important findings was that in the HIIT group, the parameters related to the AT were better or maintained at the same level after the 8-week intervention even with the progression of pregnancy and weight gain. Interestingly, the HIIT intervention reduced the %FM and improved the lean body mass of the pregnant women. In contrast, in the EDU group we observed a substantial deterioration in parameters related to the AT, and the body composition did not change significantly. Consequently, our online HIIT program may be used to prevent the pregnancy-related risk of excessive weight gain and reduction in exercise capacity as well as during the COVID-19 pandemic and in the case of limited access to sport facilities.

4.1. Parameters Related to the Anaerobic Threshold

Sloth et al. [45] found that short-term low-volume HIIT (2–8 weeks) was efficacious in increasing the VO_2/AT in healthy but sedentary adults as well as recreationally active adults and that the 4-week HIIT increased the VO_2/AT by 13% in healthy older adults [46]. In addition to the VO_2/AT, we examined other parameters related to the AT that included the HR/AT, VO_2/AT, $\%VO_{2max}$/AT, time between the HR/AerT and HR/AT, and time above the HR/AT. We observed that the VO_2/AT, HR/AT, and $\%VO_{2max}$/AT of the healthy pregnant women did not increase over the 8 weeks of HIIT (Figure 4). Nevertheless, these outcomes seemed to be beneficial when considering the progression of pregnancy and physiological weight gain during these 8 weeks of intervention. Thus, the effectiveness of HIIT in pregnant women should not be ignored. Soma-Pillay et al. [47] reported that the cardiorespiratory workload increased with fetal growth and oxygen consumption during pregnancy. In a study by Melzer et al. [48], cardiorespiratory fitness and the AT decreased during pregnancy as the body weight and cardiorespiratory load increased. In our study, the values of HR/AT and VO_2/AT significantly decreased in the EDU group but did not deteriorate in the HIIT group (Figure 4). What is more, after the interventions, the values of HR/AT and VO_2/AT were significantly higher in the HIIT group than in the EDU group.

Our observations may encourage pregnant women, including non-athletes, to participate in high-intensity interval training. This in turn may broadly support women's health and the normal course of their pregnancies because increasing the AT is associated with improved exercise capacity and cardiovascular fitness and a decreased risk of maternal mortality during the COVID-19 pandemic [3]. Our findings were in line with the studies by other authors who also noted beneficial effects of prenatal HIIT on cardiopulmonary outcomes [14].

4.2. Body Weight and Composition

The BMI and weight considerably increased in both HIIT and EDU groups but remained within the normal range specified for pregnancy. Our outcomes were similar to the findings of Ong et al. [49]. The Institute of Medicine recommends that women with a normal pre-pregnancy BMI increase their weight by approximately 5–6 kg during their second and third trimesters [50]. Much of the weight gain during the second trimester is attributed to physiological changes (e.g., increased blood volume, uterus size, breast volume, and fat storage) [51]. Despite regular exercise, pregnancy weight and BMI continue to increase throughout pregnancy [52].

One of the key findings of our study was that the %FM significantly decreased after the HIIT intervention (Figure 5). It is possible for individuals within the same BMI category to have significantly different amounts and distributions of body fat, thereby yielding differing health risks. For instance, fat mass is associated with an increased risk of cardiovascular disease mortality in individuals with a normal BMI [53,54]. Trunk fat mass is also a strong indicator of unfavorable metabolic characteristics (e.g., insulin resistance) associated with an increased risk of cardiovascular disease [55]. Furthermore, the %FM in pregnancy is positively associated with blood glucose, blood pressure, and insulin resistance, which are strongly associated with adverse pregnancy outcomes and gestational diabetes [6]. Accordingly, fat mass may play an important role in the onset of cardiometabolic disease and diabetes during pregnancy. Our online HIIT intervention provided a convenient way to exercise at home during the COVID-19 lockdown [56,57] and regulated the growth of fat mass during pregnancy more effectively. Thus, it may help pregnant women maintain a healthy lifestyle and reduce the risk of contracting COVID-19 during social gatherings.

4.3. Correlation of the Changes in the Parameters Related to the Anaerobic Threshold and Body Composition with the Characteristics of the Exercise Intervention

The exercise intervention characteristics were associated with changes in several parameters related to the AT. In the HIIT group, the number of HIIT sessions was positively correlated with the changes in the VO_2/AT; the number of self-performed sessions with the changes in the VO_2/AT and $\%VO_{2max}$/AT; and the total number of sessions with the changes in the HR/AT, VO_2/AT, and $\%VO_{2max}$/AT (Figure 6). In contrast, the number of self-performed sessions was negatively related to the changes in the VO_2/AT and $\%VO_{2max}$/AT among the pregnant women who received only the educational intervention and were encouraged to undertake physical activity on their own. Accordingly, the HIIT program under the guidance of a professional exercise specialist had a stronger effect on exercise capacity. The HIIT group was instructed on how to perform high-intensity exercises and educated about the safety and benefits of HIIT for their pregnancy progression and their unborn child's development. The fear for the child's safety was assumed to be a substantial barrier to participating in more intense activities. The use of an online, supervised HIIT intervention combined with education not only guaranteed accurate and safe exercise but was also more effective than educational intervention alone [58]. In our study, the EDU group undertook less intense physical activity (RPE of 5 ± 2 on the 0–10 Borg RPE Scale), which probably limited the effectiveness of the intervention on the exercise-capacity parameters. These findings may serve as a foundation for future recommendations regarding high-intensity exercise during pregnancy.

Notably, the %FM significantly decreased following the 8-week HIIT intervention, but the reduction was not related to the number of HIIT sessions or the intensity of each session. Scientists have speculated that the fat-burning effects of HIIT may not be attributed to the direct burning of fat during HIIT but rather to the body's increased ability to metabolize fat during daily activities and exercise. The body obtains most of its metabolic energy from the decomposition of carbohydrates when the exercise intensity is over 85% of the VO_{2max} [58]. In our study, the intensity of the HIIT intervention was expected to be greater than the AT. The interval portion of the HIIT session was probably based at least to some extent on anaerobic glycolysis for energy metabolism. The better exercise-capacity parameters in the HIIT group could be associated with the improved utilization of fat during routine daily activities, thereby resulting in a lower %FM after 8 weeks of HIIT.

Another interesting issue that we observed in our study was the different rate of dropout from the study between the HIIT and EDU groups (3% vs. 31%). The women from the HIIT group became very involved in the intervention. Only one participant resigned after a few classes due to family duties. We suspect that women who received the supervised exercise program were significantly more motivated and likely more willing to overcome the barriers to attending classes. Our observations were in line with the works by other authors. For example, Anderson et al. [59] found that pregnant women considered HIIT sessions to be more "interesting" and "challenging" and that they provided a "better workout" and made time "go faster" compared to continuous training. Halse et al. [60] noted that a HIIT cycling program enhanced pregnant women's attitudes and intentions toward exercise. Training enjoyment is of particular importance because it significantly predicts exercise adherence [61], which consequently may determine desired health benefits. The analysis of the motivation of pregnant women to participate in our HIIT intervention is worthy of further research.

In turn, the high dropout rate in the comparative group may have resulted from the feeling that they did not get what they came to the study for. The EDU group also consisted of women who were potentially interested in physical activity and probably felt disappointed by their allocation to the educational intervention. Apart from the premature labor (which was not related to physical activity or other lifestyle factors) in one participant, other reasons for discontinuation of the intervention reported by the EDU group appeared to be possible to overcome with appropriate incentive strategies and counseling. However, the online lectures once a week did not seem sufficient in this regard.

4.4. Strengths and Limitations

To our knowledge, this was the first study to assess the effects of a HIIT program on the parameters related to the AT and body composition of women with uncomplicated pregnancies. The strength of our work is that it evaluated the outcomes of 8-week HIIT intervention. Most of the available studies in human populations assessed the acute effects of a single HIIT session. Longer HIIT interventions lasting for several weeks were conducted in animal models [14]. In addition, the online mode of provision of our interventions (both HIIT and educational) may serve as solutions to maintain a sufficient level of physical activity in pregnant women during future lockdowns as during the COVID-19 pandemic. Outside the pandemic period, the online provision of HIIT programs can be a good solution for pregnant women who have limited access to sport facilities, who lack the time to travel to the gyms, or who need to stay home (e.g., due to family reasons, including taking care of older children).

Nevertheless, our work had some limitations that should be considered when evaluating the conclusions. First, we only recruited pregnant women of a single ethnicity to minimize the degree of heterogeneity among the participants. Despite being likely representative of a demographic and socially similar population, the findings may be limited in their application to other races. Second, no information regarding dietary intake was obtained. In pregnant women, protein supplementation may enhance the beneficial effects of HIIT. Another weak point of our work was that we did not compare our intervention to other online exercise programs. Certainly, our educational group seemed to be an interesting comparative group because it represented pregnant women under standard obstetric care. In accordance with the current guidelines [13], all pregnant women should obtain information on a healthy lifestyle, including on physical activity, from their obstetric care providers. However, the comparison of the effectiveness of online prenatal HIIT to an online moderate-intensity continuous program would be very valuable.

Further research is needed to investigate the above-mentioned issues. In future work, it would be also interesting to estimate the impact of our HIIT intervention in those pregnant participants who performed less than 70% of the entire exercise program; e.g., using intention-to-treat (ITT) analyses with linear interpolation. Another valuable question regards how long the better exercise capacity outcomes remain after delivery. Such an analysis could have a practical value in developing recommendations on the implementation of pre-natal and post-natal HIIT programs.

5. Conclusions

Our 8-week online HIIT program had a positive impact on the exercise capacity and the body composition in women with uncomplicated pregnancies without producing adverse obstetric and neonatal effects. Despite physiological pregnancy weight gain and pregnancy progression, after the HIIT intervention the parameters related to the AT were better or maintained at the same level. What is more, the %FM decreased in this group. Our findings indicated that online, supervised HIIT combined with education on a healthy lifestyle during pregnancy had a greater impact on health parameters than education alone. It seems likely that similar interventions are necessary for pregnant women with multiple or complicated pregnancies or other races if HIIT programs are to be popularized widely among pregnant women. This online protocol can potentially promote exercise programs during the COVID-19 pandemic and in situations where women have limited time or access to sport facilities.

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Institutional Review Board Statement: This study was conducted in accordance with the principles of the Declaration of Helsinki of the WMA and approved by the Bioethics Commission of the District Medical Chamber in Gdansk (KB-8/21). The full study protocol was registered with ClinicalTrials.gov (NCT05009433). No important methodological changes were made after the commencement of the trial. The study followed the standards for transparency, openness, and reproducibility of research and adhered to the CONSORT standards.

Informed Consent Statement: The participants provided informed consent before testing.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author (H.Y.) or the project head (A.S.) upon reasonable request.

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Conflicts of Interest: The authors declare no conflict of interest.

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