Cardiorespiratory variable responses in deep water running and treadmill running crossover tests: a systematic review

Respuestas de las variables cardiorrespiratorias en pruebas cruzadas de carrera en aguas profundas y carrera en cinta: una revisión sistemática

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Abstract

Cardiorespiratory fitness (CRF) is a key marker of health and performance, commonly assessed through treadmill running (TR). However, deep-water running (DWR) has emerged as an alternative modality, minimizing joint impact while preserving cardiovascular stimuli. Despite its potential, inconsistencies in CRF responses between TR and DWR remain unexplored in a systematic synthesis. To systematically review and compare the cardiorespiratory responses of maximal CRF tests performed in DWR and TR. This systematic review followed the PRISMA guidelines and was registered in PROSPERO (CRD42021260382). Searches were conducted in PubMed, Scielo, Embase, Scopus, and Web of Science, without publication date restrictions. Inclusion criteria encompassed studies assessing healthy adults (18–59 years) performing maximal CRF tests in both DWR and TR. Cardiorespiratory variables analyzed included VO_2max, heart rate (HR), pulmonary ventilation (VE), and respiratory exchange ratio (RER). Study quality was assessed using the TESTEX scale. Fourteen studies comprising 225 participants met the inclusion criteria. VO_2max values in DWR ranged from 76% to 90% of those observed in TR. HR, VE, and blood lactate accumulation were significantly lower in DWR, whereas perceived exertion remained similar. Differences were attributed to hydrostatic pressure, reduced activation of antigravity muscles, altered biomechanics, and enhanced thermoregulation. TR elicits higher cardiometabolic demands than DWR. While DWR is a submaximal alternative, its prescription should be based on aquatic-specific testing. Future studies should refine standardized protocols and investigate chronic adaptations.

Keywords

Cardiorespiratory fitness; Deep-water running; Treadmill running; VO_2max.

Resumen

La aptitud cardiorrespiratoria (CRF) es un marcador clave de salud y rendimiento, evaluado comúnmente a través de la carrera en cinta rodante (TR). Sin embargo, la carrera en aguas profundas (DWR) ha surgido como una modalidad alternativa, minimizando el impacto articular mientras preserva los estímulos cardiovasculares. A pesar de su potencial, las inconsistencias en las respuestas de la CRF entre TR y DWR no han sido exploradas en una síntesis sistemática. Revisar y comparar sistemáticamente las respuestas cardiorrespiratorias de las pruebas máximas de CRF realizadas en DWR y TR. Esta revisión sistemática siguió las directrices PRISMA y fue registrada en PROSPERO (CRD42021260382). Se realizaron búsquedas en PubMed, Scielo, Embase, Scopus y Web of Science, sin restricciones de fecha de publicación. Los criterios de inclusión abarcaron estudios que evaluaron adultos sanos (18–59 años) realizando pruebas máximas de CRF en DWR y TR. Las variables cardiorrespiratorias analizadas incluyeron VO_2max, frecuencia cardíaca (FC), ventilación pulmonar (VE) y cociente respiratorio (RER). La calidad de los estudios se evaluó mediante la escala TESTEX. Se incluyeron catorce estudios con un total de 225 participantes. Los valores de VO_2max en DWR oscilaron entre el 76% y el 90% de los observados en TR. La FC, la VE y la acumulación de lactato sanguíneo fueron significativamente menores en DWR, mientras que la percepción del esfuerzo se mantuvo similar. Estas diferencias se atribuyeron a la presión hidrostática, la reducción de la activación muscular antigravitatoria, las modificaciones biomecánicas y la mejora de la termorregulación. La TR impone mayores demandas cardiometabólicas que la DWR. Aunque DWR es una alternativa submáxima, su prescripción debe basarse en pruebas específicas para el medio acuático. Futuros estudios deben refinar los protocolos estandarizados e investigar las adaptaciones crónicas.

Palabras clave

Aptitud cardiorrespiratoria; Carrera en aguas profundas; Carrera en cinta rodante; VO_2max

Introduction

Cardiorespiratory fitness (CRF) reflects the body's ability to uptake and transport oxygen from the atmosphere to the mitochondria, where it is utilized for physical exertion. This measure depends on the efficient integration of the cardiovascular, muscular, and pulmonary systems and is considered an important biomarker of health and physical capacity (Ross et al., 2016).

CRF assessment is often conducted through cardiopulmonary exercise testing, which provides indicators such as maximal oxygen consumption (VO_2max) and maximal heart rate during exertion. These and other parameters are essential for an individual’s clinical prognosis and serve as fundamental data for the precise and effective prescription and planning of physical exercise (McArdle et al., 2016; Ross et al., 2016).

In this context, CRF testing is frequently performed on treadmills, using running as the primary modality. However, treadmill running can increase the risk of musculoskeletal injuries due to ground impact, particularly affecting structures such as the knees, ankles, and feet (Araújo et al., 2015). Therefore, this factor must be considered when assessing populations for whom CRF evaluation is necessary but who cannot tolerate excessive joint loading. Additionally, in high-volume training scenarios, athletes may experience joint overload from treadmill or overground running, yet they still need to continue training to maintain or improve this capacity.

As an alternative form of physical exertion, deep water running (DWR) has been proposed. This modality is performed in an aquatic environment, with the body submerged up to shoulder level, with or without the aid of flotation devices (Micdeep Wahaud et al., 1995). DWR stands out for significantly reducing joint impact while offering substantial benefits related to cardiorespiratory adaptation, physical function, and quality of life (Bushman, 2012; Kwok et al., 2022). Consequently, CRF assessment tests have been specifically adapted for DWR, demonstrating its potential as a tool for cardiorespiratory measurement (Silva et al., 2010) and also as a means of training to maintain or improve this CRF.

Nevertheless, the analysis of original studies reveals discrepancies in the results of CRF tests conducted with DWR compared to treadmill running (TR), which poses challenges in understanding the relationship between both modalities and their respective applications (Brown et al., 1996; Chu et al., 2002; Kanitz et al., 2014).

In this context, there is a notable absence of systematic reviews synthesizing these data and analyzing the topic. Therefore, the objective of this systematic review was to compare cardiorespiratory responses between CRF tests using DWR and TR.

Method

The present systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method and was registered in the international database PROSPERO under the registration number CRD42021260382. The searches were performed in the PubMed, Scielo, Embase, Scopus, and Web of Science databases, with no restrictions on the date of publication, considering studies available up to September 2024.

The descriptors used included "running", selected from Medical Subject Headings (MeSH), combined with keywords identified in studies related to the topic, such as deep water running, land running, treadmill running, and cardiorespiratory responses. The search strategy applied was: “deep water running AND running OR land running OR treadmill running AND cardiorespiratory responses”. Additionally, in the Web of Science database, a filter was applied to restrict the results to the study titles.

To define the inclusion and exclusion criteria, the PICOT strategy was used, which considers Population, Intervention, Comparator, Outcomes, and Study Type. Accordingly, studies were included if they assessed adults aged 18 to 59 years, defined by the authors as healthy and either physically active or inactive. The intervention analyzed involved maximal exercise tests in the DWR modality, while the comparator consisted of TR. The outcomes evaluated included differences in cardiorespiratory measures, such as maximum oxygen consumption (VO_2máx), heart rate (HR), pulmonary ventilation (VE), and respiratory exchange ratio (RER). Studies involving unhealthy populations, animal models, case studies, reviews, and those that did not compare tests conducted in different environments were excluded from the analysis.

The article selection process was conducted in three stages. Initially, the studies were exported to Endnote software (Endnote X9, Thomson Reuters, USA) for duplicate removal. Then, the references were analyzed by screening the titles and abstracts to assess their relevance to the review topic, excluding incompatible articles. Finally, the remaining studies were read in full to confirm whether they met the predefined inclusion criteria for this review.

Quality Assessment of the Studies

The quality of the studies was assessed in duplicate and independently using the Tool for the assessment of Study qualiTy and reporting in Exercise (TESTEX) scale. TESTEX is an instrument for assessing studies related to physical training and has 15 points (5 of which refer to the quality of the study and 10 to the study reports). The higher the score achieved on the scale, the higher the quality of the research and report there is in the article (Smart et al., 2015). The assessment was performed in duplicate and independently and proved to be quite homogeneous, presenting results ranging from 9 to 12 points, demonstrating reasonable to good quality among the studies. The details of the assessment of the selected studies can be found in Table 1.

Table 1. Analysis of the methodological quality of the included studies

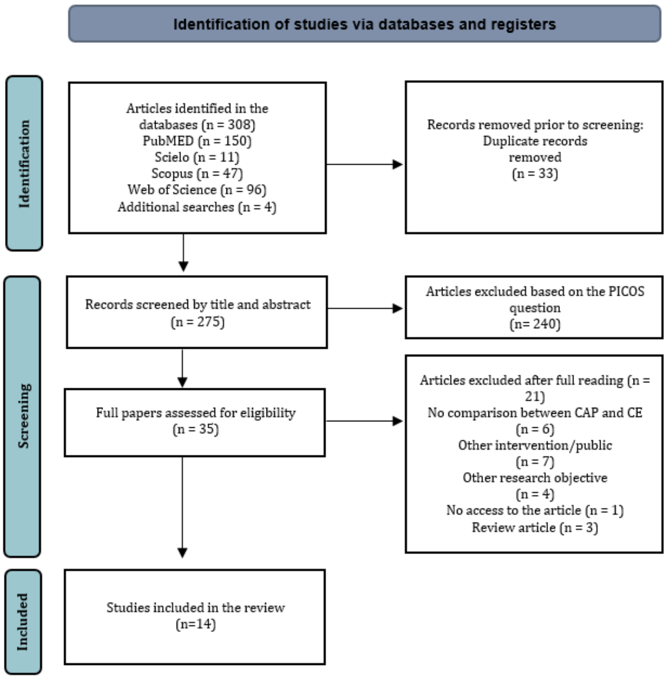
Study	Study quality					P (0 a 5)	Study report										P (0 a 10)	T(0 – 15)
	1	2	3	4	5		6a	6b	6c	7	8a	8b	9	10	11	12		
Chu et al. (2002)	1	0	0	1	0	2	1	0	1	1	1	1	1	1	0	1	8	10
Kanitz et al. (2014)	1	0	0	1	0	2	1	0	1	1	1	1	1	1	0	1	8	10
Butts et al. (1991)	1	1	0	0	0	2	1	1	1	1	1	1	0	1	0	1	8	10
Brown et al. (1996)	1	0	0	1	0	2	1	0	1	1	1	1	0	1	0	1	8	9
Masumoto et al. (2018)	1	0	0	1	0	2	0	1	1	1	1	1	1	1	0	1	8	10
Azevedo et al. (2010)	1	0	0	0	0	1	1	0	1	1	1	1	1	1	0	1	8	9
Tiggemann et al. (2007)	1	0	0	1	0	2	1	0	1	1	1	1	1	1	0	1	8	10
Dowzer et al. (1999)	1	0	0	1	0	2	1	0	1	1	1	1	1	1	0	1	8	10
Nakanishi et al. (1999)	1	0	0	1	0	2	1	0	1	1	1	1	1	1	0	1	8	10
Wilber et al. (1996)	1	0	0	1	0	2	1	0	1	1	1	1	1	1	1	1	9	11
Frangolias e Rhodes (1995)	1	1	0	1	0	3	1	0	1	1	1	1	1	1	1	1	9	12
Svedenhag e Seger (1992)	1	0	0	1	0	2	1	1	0	1	1	1	1	0	1	1	8	10
Michaud et al. (1995)	1	0	0	1	0	2	0	1	1	1	1	1	1	1	1	1	8	11
Mercer e Jensen (1998)	1	1	0	1	0	3	1	0	1	1	1	1	1	1	1	1	9	12

Outcome measures assessed in 85% of participants (6a = 1 point if completion rate >85%; 6b = 1 point if adverse events were reported; 6c = 1 point if exercise frequency was reported); 7 = Intention-to-treat analysis; 8 = Statistical between-group comparisons reported (8a = 1 point if statistical between-group comparisons were reported for the primary outcome measure of interest; 8b = 1 point if statistical between-group comparisons were reported for at least one secondary outcome measure); 9 = Point measures and measures of variability for all outcome measures reported; 10 = Activity monitoring in control groups; 11 = relative exercise intensity remained constant; 12 = Exercise volume and energy expenditure.

Results

Initially, the search returned 308 articles. After removing duplicates, 275 articles remained for reading titles and abstracts. After reading titles and abstracts, 35 articles remained for reading the full text. After reading the full texts, 20 articles were excluded because they did not meet the inclusion criteria for this review and 1 because it was not accessible, leaving 14 articles for analysis and construction of the review. The search process can be seen in Figure 1.

Figure 1. Prisma Flow diagram of the selection steps in the databases.



Characterization of studies and subjects

A total of 225 individuals were analyzed in the studies included in this review, comprising 135 men and 90 women, with an age range between 18 and 59 years.
In ten studies (Kanitz et al., 2014; Butts et al., 1991; Brown et al., 1996; Masumoto et al., 2017; Azevedo et al., 2010; Tiggemann et al., 2007; Dowzer et al., 1999; Frangolias et al., 1995; Svendenhag and Seger, 1992; Frangolias et al., 1996), the sample consisted of physically active individuals and/or short- and long-distance runners. Conversely, in three studies (Chu et al., 2002; Nakanishi et al., 1999; Michaud et al., 1995), the analyzed population was characterized as physically inactive or sedentary.

Regarding the objectives of the studies included in this review, several investigations compared the physiological responses between deep-water running (DWR) and treadmill running (TR) (Kanitz et al., 2014; Butts et al., 1991; Downzer et al., 1999; Frangolias et al., 1995, 1996; Tiggerman et al., 2007). Other studies analyzed variables related to subjective perception of effort and metabolic demand in these different conditions (Brown et al., 1996; Svendenhag and Seger, 1992). In another study (Masumoto et al., 2017), muscle activation responses and biomechanics were examined. Additionally, comparisons of maximal and submaximal physiological responses in the tests were performed (Azevedo et al., 2010; Michaud et al., 1995), as well as the effects of age on these responses (Nakanishi et al., 1999). Lastly, one study evaluated test-retest reliability in assessing physiological responses between tests (Mercer and Jensen, 1997). Thus, these studies provide a relevant scientific foundation for understanding the physiological differences between DWR and TR.

Test characterization

Regarding the evaluation order, most of the included studies implemented randomization for test execution and considered familiarization sessions and/or periods for the DWR test. Notably, two studies (Frangolias et al., 1995; Frangolias et al., 1996) included participants who were highly trained in DWR, while another study (Azevedo et al., 2010) divided participants into two groups (familiarized and non-familiarized) to compare the physiological responses of both groups in DWR.

Regarding environmental conditions, the air temperature during treadmill tests ranged from 21°C to 26°C, while in DWR, water temperature fluctuated between 25°C and 32.5°C. Concerning the interval between tests, all studies incorporated a rest period ranging from 1 to 14 days.

In terms of DWR protocols, all studies employed some type of flotation device, such as a vest or belt. Additionally, some studies (Azevedo et al., 2010; Brown et al., 1996; Butts et al., 1991; Dowzer et al., 1999; Mercer and Jensen, 1997) utilized elastic bands or ropes attached to the pool's edge and to the belt/vest to ensure that the running technique was maintained in place without displacement. In other studies (Kanitz et al., 2014; Masumoto et al., 2017; Nakanishi et al., 1999), participants were not tethered and moved freely, whereas in another study (Tiggerman et al., 2007), the vest was attached to a pulley system, adding resistance to movement.

Regarding the movement pattern applied in DWR, studies encouraged participants to follow a terrestrial running-like motion, and in some cases, to use the high-knee running technique, lifting the knees as high as possible while maintaining flexed elbows in a vertical position. The intensity increment was achieved through step cadence increase, mechanical resistance, or progressive load increase.

For treadmill running tests, protocols involved increments in speed and/or incline, with stages lasting between 1 and 2 minutes, and test termination criteria based on exhaustion and/or a respiratory exchange ratio (RER) > 1.1. All these data are summarized in Table 2.

Table 2. Sample characteristics, test protocols and study objectives

Study	Sample characteristics	Sample data	DWR protocol	Objectives
(Masumoto et al., 2017)	10 M and 1 W recreational runners	22.6 ± 2.6 years; 174.1 ± 6.1 cm; 74.4 ± 9.4 kg	With the water at shoulder height, the recommended running motion was like gesturing up some stairs. Otherwise, the protocol followed that proposed by Michaud et al. (1995)	Investigating muscle activity during deep water running and treadmill running
(Kanitz et al., 2014)	12W physically active	23.2 ± 1.9 years; 161.4 ± 5.6 cm; 57.9 ± 7.1 kg	The protocol began with 85 beats per minute for 3 minutes, followed by increments of 15 beats/minute every 2 minutes until the participant reached exhaustion	To compare the maximal cardiorespiratory responses and the AT during maximal TR and DWR tests
(Azevedo et al., 2010)	11W and 6M recreational runners	7 NA = (30.9 ± 5.3 years; 165 ± 6 cm; 59.8 ± 6.1 kg) 10 A = (32.3 ± 6.5 years; 172 ± 12 cm; 68.9 ± 17.1 kg)	The protocol followed the recommendations of Michaud et al. (1995)	To compare maximal and submaximal physiological responses in runners following similar deep water running and treadmill training who were adapted to water running and unadapted
(Tiggerman et al., 2007)	5 healthy physically active	22 ± 1.3 years; 160 ± 5.5 cm; 55 ± 8.2 kg	The water running test consisted of continuing to run for the rest of the run, while a vest with an initial load of 500g was receiving increments of 250g every minute, until exhaustion	To compare maximal cardiorespiratory variables between treadmill running and deep water running in active young women familiar with deep water running
(Chu et al., 2002)	9 W physically inactive	23.6 ± 4.7 years; 165.5 ± 3.6 cm; 58.4 ± 8.5 kg	Running in stationary water, starting with a 500g vest and increasing the vest by 200g every minute until exhaustion or RER > 1.1	Investigate the responses of DWR compared with TR in elderly women and to determine whether these responses are similar to those of young women
(Downzer et al., 1999)	15 M runners	40.9 ± 9.4 years; 172 ± 7 cm; 69 ± 9 kg	The deep water race started at a pace of 120 strides per minute and increased in increments of 12 strides per minute until exhaustion	To verify the physiological responses of deep water running, shallow water running and treadmill running
(Nakanishi et al., 1999)	28 M healthy sedentaries	Y = (20.4 ± 3.3 years; 170.7 ± 6.2 cm; 65.1 ± 11.4 kg) MY = (38.6 ± 4.4 years; 171.8 ± 4.7 cm; 75.4 ± 9.6 kg)	The test followed the Wilder/Brennan protocol, starting with an initial pace of 48 cycles/min for 4 minutes, followed by a second stage with 66 cycles/min and so on in increments of 3 to 4 cycles/min. When participants could no longer maintain the cadence, they were encouraged to go "all out" so that they could withstand another 1 minute of the final stage	To understand the effects of age factors on physiological responses in deep water running compared to those obtained in treadmill running
(Mercer and Jensen, 1997)	12 W and 14 M	12W = (21 ± 1.2 years; 1.68 ± 0.11 m; 59.7.3 kg) 14M = (24 ± 4.9 years; 1.79 ± 0.08 m; 79 ± 10.9 kg)	Participants used a floating belt that was attached to a 0.57 kg load along with a pulley system. As the subject's performance decreased, the pulley would pull, so that the counterweight in the bucket at the end of the pulley would touch the deck, where the test would stop	To verify the test-retest feasibility of verifying VO2peak and Fcpeak during the deep water running test, using weights and pulley systems
(Brown et al., 1996)	12 W and 12 M healthy and	W = (20 ± 0.8 years; 168.5 ±	The test started with 72 steps per minute and every 3 minutes there was an increment of 12 steps. The	To compare RPE responses between treadmill testing and

	moderately active	4.7 cm; 60.4 ± 7.3 kg) M = (21 ± 1.9 years; 179.7 ± 4.8 cm; 77.2 ± 12 kg)	participants were only allowed to move their arms in a pendulum motion, but without lifting their arms out of the water. The leg movement technique was kept uniform. The subjects were instructed to move their legs during the simulated run to a flexed position of 45 degrees of hip flexion and to a hyperextended position of 10 degrees of hip hyperextension.	deep water running at similar speed stages and to compare these responses in men and women.
(Frangolias et al., 1996)	8 W and 14 M endurance runners	26.3 ± 4.7 years; 176.2 ± 9 cm; 63.4 ± 8.7 kg	The water testing protocol was designed to be similar to the treadmill protocol in terms of duration and progression. The incremental test consisted of starting with a load of 500 g and 750 g per vest for women and men, respectively, followed by increments of 500 and 750 g every minute until exhaustion.	Compare cardiorespiratory responses between treadmill and water running tests
(Frangolias et al., 1995)	13 elite distance runners trained in water running	5W = (24.2 ± 6.7 years; 165.6 ± 4.3 cm; 54.2 ± 4.9 kg) 8M = (27.3 ± 4.1 years ; 182.5 ± 5 cm; 71.5 ± 4.6 kg)	The protocol followed the recommendations of Frangolias et al. (1996)	To compare the physiological and metabolic demands of maximal treadmill testing and maximal water running in elite distance runners adapted to water running
(Michaud et al., 1995)	8 W and 2 M sedentaries	32.6 ± 6.8 years; 172.1 ± 7.5 cm; 76.6 ± 13.3 kg	The arms were flexed at 90 degrees and the arms moved in the sagittal plane, starting at the shoulders. Running in the water simulated running on land and the participants were encouraged to reach 70 degrees of hip flexion. The movement then flowed with the legs almost fully extended. The test began with a cadence of 48 cycles per minute, followed by increasing steps every 3 minutes	To investigate the effects of 8 weeks of aerobic training with deep water running on cardiorespiratory fitness
(Svendenhag and Seger, 1992)	9 M long distance runners	26.4 (17 – 35) years; 182 (171 - 191) cm; 70.2 (63.2 - 92.6) kg	The protocol consisted of using a floating vest and performing the running gesture close to the edge of the pool and along the pool. Followed by a 5-minute warm-up, followed by 4 periods of 4 minutes with a self-selected stride frequency. After this, maximum speed was stimulated so that the participant could tolerate at least 1 minute at this intensity	To compare the physiological responses of runners trained in shallow water running, deep water running and treadmill running
(Butts et al., 1991)	12 W and 12 M physically active runners	W = (21.9 ± 2.4 years; 164.6 ± 4.2 cm; 59.6 ± 6.4 kg) M = (20.6 ± 1.9 years; 178.2 ± 6.6 cm; 70.5 ± 7.3 kg)	At the beginning, participants began the test at a cadence speed of 10 beats per minute and increments of 20 beats every minute. When the participants could not maintain the cadence or when their physiological responses did not increase further, even with the increase in intensity, they were encouraged to give it their all so that they could complete at least 1 more minute.	To compare the physiological responses to running in water and on a treadmill in male and female runners

W = Women; **M** = Men; **A** = Adapted to water running; **NA** = Not adapted to water running; **Y** = Young people; **MY** = Middle Young; DWR = Deep water running; TR = treadmill running.

Assessment of cardiorespiratory fitness

All studies included in this review primarily aimed to compare the responses of cardiorespiratory variables obtained from maximal DWR and TR tests. Furthermore, it was observed that in all included studies, except for one (Azevedo et al., 2010), the tests reached a RER of 1.05 or higher, which may indicate a maximal test.

Regarding VO_2max measurement, values were reported in both absolute and relative terms. In general, VO_2max values in DWR accounted for approximately 76% to 90% of those observed in TR tests. Lower values were also observed for cardiometabolic responses, including maximal heart rate, blood lactate concentration, and pulmonary ventilation.

Additionally, greater adaptation to DWR, younger age, and being male appear to contribute to improved cardiometabolic responses during deep-water running (Azevedo et al., 2010; Nakanishi et al., 1999; Mercer and Jensen, 1997; Brown et al., 1996; Butts et al., 1991).

In contrast, for subjective perception of effort, most studies found that RPE were similar between tests, with both reaching values above 17 on Borg's 0-20 RPE scale. Furthermore, despite participants being already adapted to DWR in some conditions, cardiorespiratory and metabolic demands remained lower than those observed in TR. This finding reinforces that DWR is a submaximal modality compared to TR. All results related to the variables obtained from the cardiorespiratory tests can be seen in Table 3.

Table 3. Summarized values of cardiorespiratory responses in the tests.

Study	VO2máx (l/min)	VO2máx ml/kg/min	FCmáx (bpm)	Blood lactate (mmol/min)	VE (l/min)	RER
(Masumoto et al., 2017)	3.63 ± 0.58	48.9 ± 5.7	174.1 ± 9.6	-	-	-
	4.43 ± 0.48	59.2 ± 5.6	191.2 ± 6.9	-	-	-
(Kanitz et al., 2014)	1.4 ± 0.4	22.5 ± 4.1	174 ± 9	-	-	-
	2.1 ± 0.3	33.7 ± 3.9	190 ± 5			
(Azevedo et al., 2010)	-	NA = 44.3 ± 3.3 A = 48.3 ± 8.4	NA = 172 ± 13 A = 177 ± 11	NA = 8.0 ± 1.2 A = 7 ± 1.4	NA = 88.5 ± 16.1 A = 106.2 ± 29	NA = 0.97 ± 0.14 A = 1.09 ± 0.12
	-	NA = 55.1 ± 4.2 A = 53.8 ± 6	NA = 186 ± 11 A = 186 ± 9	NA = 102.5 ± 12.9 A = 121 ± 22.4	NA = 9.3 ± 2.0 A = 9.6 ± 1.9	NA = 0.99 ± 0.11 A = 1.10± 0.11
(Tiggerman et al., 2007)	1.68 ± 0.31	30.3 ± 4.75	185 ± 9.8	-	63.78 ± 5.7	-
	2.16 ± 0.37	38.86 ± 3.15	195.2 ± 8.7	-	73.4 ± 6	-
(Chu et al., 2002)	2.46 ± 0.38	43.17 ± 9.11	182.3 ± 9.1	8.62 ± 2	80.9 ± 10.4	1.11 ± 0.06
	2.7 ± 0.3	47± 8.8	192.3 ± 8.7	8.99 ± 1.38	82.9 ± 14.4	1.18 ± 0.09
(Downzer et al., 1999)		41.27 ± 6.37	153 ± 16	-	110.9 ± 17	1.08 ± 0.1
		55.39 ± 8.46	176 ± 12		137.1 ± 21.9	1.11 ± 0.1
(Nakanishi et al., 1999)	Y = 2.51 ± 0.53 MY = 2.25 ± 0.47	Y = 39 ± 7.8 MY = 30.2 ± 7.1	Y = 169.2 ± 15.1 MY = 158.4 ± 19.7	Y = 9.2 ± 3 MY = 10.1 ± 2.8	Y = 89.4 ± 18.2 NY = 81.7 ± 20.8	Y = 1.03 ± 0.07 MY = 1.06 ± 0.07
	Y = 3.2 ± 0.52 MY = 3.08 ± 0.47	Y = 49.5 ± 7.6 MY = 41.3 ± 8	Y = 193.9 ± 6.7 MY = 183.3 ± 13.4	Y = 13.8 ± 3.3 MY = 11.9 ± 3.1	Y = 107 ± 18 MY = 104 ± 18.4	Y = 1.07 ± 0.04 MY = 1.06 ± 0.05
(Mercer and Jensen, 1997)	W = 2.2 ± 0.28 M = 4.1 ± 0.95	W = 37 ± 5.16 M = 51.2 ± 11.32	W = 182 ± 7.1 M = 174 ± 9.1	-	-	W = 1.34 ± 0.10 M = 1.31 ± 0.10
	W = 2.7 ± 0.37 M = 5 ± 0.11	W = 46.6 ± 5.8 M = 63 ± 11.96	W = 192 ± 7.3 M = 187 ± 8.9	-	-	W = 1.3 ± 0.10 M = 1.31 ± 0.08
(Brown et al., 1996)	-	W = 30.1 ± 3.1 M = 39.1 ± 8.3	W = 173.9 ± 7.3 M = 183.8 ± 7.7	-	-	-
		W = 40.1 ± 3.1 M = 45.2 ± 4.4	W =194.6 ± 5 M = 195.7 ± 5.2			
(Frangolias et al., 1996)	-	53.8 ± 5.4	172 ± 14	-	104.4 ± 19.2	1.12 ± 0.04
	-	58.8 ± 6.2	187.7 ± 12.5	-	106.6 ± 21.6	1.19 ± 0.07
(Frangolias et al., 1995)	3.6 ± 0.78	54.6 ± 5.2	175 ± 12	-	105.8 ± 19.1	1.1 ± 0.06
	3.92 ± 0.89	59.7 ± 6.4	190 ± 11	-	109 ± 22.7	1.2 ± 0.08
(Michaud et al., 1995)	1.79 ± 0.59	-	172 ±16.7	-	-	1.24 ± 0.09
	2.25 ± 0.57	-	187 ± 11.9	-	-	1.29 ± 0.11
(Svendenhag and Seger, 1992)	4.03 ± 0.13	-	172 ± 3	-	-	1.1 ± 0.04
	4.6 ± 0.14	-	188 ± 2	-	-	1.2 ± 0.04
(Butts et al., 1991)	W = 2.7 ± 0.3 M = 4.0 ± 0.4	W = 46.8 ± 5.9 M = 58.4 ± 3.8	W = 179.5 ± 7.5 M = 183.4 ± 5.9	-	W = 97.7 ± 10.9 M = 140.8 ± 17.8	W = 1.09 ± 0.04 M = 1.11 ± 0.03
	W = 3.3 ± 0.3 M = 4.55 ± 0.36	W = 55.7 ± 4.8 M = 64.5 ± 2.8	W = 188.7 ± 9.3 M = 193.3 ± 5.8		W = 111.6 ± 7 M = 150.0 ± 11.6	W = 1.13 ± 0.03 M = 1.15 ± 0.04

In the white boxes, the values correspond to the tests in Deep-Water Running, while in the gray boxes, the values correspond to the tests in Treadmill Running. W = Women; M = Men; A = Adapted to water running; NA = Not adapted to water running; Y = Young people; MY = Middle Young.

Discussion

This review aimed to compare the cardiorespiratory responses between maximal running tests performed in deep water and on a treadmill. The findings consistently indicate that TR imposes higher cardiometabolic demands than deep water running (DWR), as evidenced by greater values for HR, VO_2max, pulmonary ventilation, and blood lactate accumulation. These differences can be attributed to a combination of physiological and biomechanical factors inherent to the aquatic environment, including hydrostatic pressure, reduced activation of antigravity muscles, water temperature effects, and biomechanical modifications in running mechanics.

One of the primary determinants of the attenuated cardiorespiratory responses observed in DWR is the influence of hydrostatic pressure. Water immersion facilitates venous return by shifting peripheral blood toward the thoracic cavity, increasing central blood volume and stroke volume while reducing the need for high cardiac output. This redistribution results in a lower maximal HR during DWR compared to TR (Tiggerman et al., 2007; Nakanishi et al., 1999).

Additionally, the increase in central blood volume enhances the baroreflex response, leading to reduced sympathetic activation and further decreasing HR. As a result, despite similar subjective effort perception between the two modalities (Masumoto et al., 2017), the cardiovascular system operates at a lower absolute intensity during DWR, ultimately reducing VO_2max values compared to TR.

Another key factor explaining the lower cardiorespiratory demand in DWR is the diminished activation of antigravity muscles. On land, lower limb muscles must generate significant force to counteract gravity and maintain propulsion. In contrast, the buoyancy provided by water reduces the need for such muscular engagement, lowering the overall metabolic cost of movement (Kanitz et al., 2014).

In another study (Masumoto et al., 2017) it was demonstrated that muscle activation in the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius during maximal effort DWR was 29%–69% lower than in TR. This reduction in muscle recruitment contributes to lower oxygen consumption demands, further confirming the submaximal nature of DWR, even at maximal effort.

Biomechanical differences also play a significant role in shaping the metabolic responses between these two modalities. Running in water differs considerably from running on land, primarily due to the absence of ground reaction forces. This alters neuromuscular coordination, leading to a less efficient stride pattern. The increased drag force and resistance from water further modify running mechanics, reducing stride frequency and increasing stride variability (Mercer & Jensen, 1997). Furthermore, the absence of an elastic recoil effect - normally provided by ground contact in TR - results in greater reliance on active muscle contraction for limb movement. However, due to the lower force requirements imposed by buoyancy, overall oxygen demand remains lower in DWR (Dowzer et al., 1999).

Water temperature is another important factor influencing cardiovascular responses during exercise. Due to its higher thermal conductivity compared to air, water effectively dissipates heat, reducing the need for cutaneous vasodilation and redirection of blood flow to the periphery (Kanitz et al., 2014; Tiggerman et al., 2007). In warmer water temperatures, around 30°C, mild vasodilation occurs, further decreasing sympathetic activity and cardiovascular strain. This thermoregulatory advantage contributes to the lower HR and VO_2max values observed in DWR, reinforcing its submaximal profile (Nakanishi et al., 1999).

The accumulation of blood lactate during exercise serves as a key indicator of anaerobic metabolism and metabolic stress. Studies have consistently reported lower lactate levels in DWR compared to TR at maximal intensities (Kanitz et al., 2014; Nakanishi et al., 1999). This suggests a reduced reliance on anaerobic energy pathways, likely due to a combination of factors: (i) lower muscle activation, leading to decreased glycolytic demand; (ii) enhanced venous return, facilitating more efficient lactate clearance; and (iii) reduced sympathetic drive, attenuating catecholamine-induced glycolysis.

Understanding these physiological differences is essential for optimizing training protocols. While TR elicits greater cardiorespiratory demands and is superior for maximizing aerobic capacity, DWR presents a valuable alternative for individuals requiring low-impact exercise, such as those recovering from injuries, older adults, or individuals with obesity. Furthermore, the reduced cardiometabolic strain observed in DWR highlights the importance of prescribing exercise intensity based on water-specific maximal tests rather than extrapolating from land-based assessments (Tiggerman et al., 2007). Failure to consider these adjustments may lead to over- or underestimation of training intensity, potentially compromising the effectiveness of aquatic exercise programs.

In view of this, some limitations must be considered for this review. The included studies employed heterogeneous protocols, varying in incremental load adjustments, stride frequency control, and exercise duration, which may have influenced the reported physiological responses. Additionally, differences in participant characteristics, such as training background and familiarity with DWR, could have affected movement efficiency and metabolic demands. Small sample sizes in several studies also limit the generalizability of findings, emphasizing the need for larger and more diverse populations. Furthermore, most studies focused on acute physiological responses, with limited longitudinal data assessing chronic adaptations to DWR training. Environmental factors, such as water temperature, pool depth, and turbulence, were not consistently controlled, potentially introducing variability in the results.

Future research should prioritize standardized testing protocols, biomechanical assessments using motion capture and electromyography, and well-controlled longitudinal studies to determine the long-term adaptations to DWR. Additionally, given the lower cardiometabolic demand observed in water, developing specific intensity guidelines tailored to aquatic exercise is crucial to enhance training prescription accuracy. Addressing these limitations will contribute to a more comprehensive understanding of DWR and its applications in both athletic performance and rehabilitation settings.

Conclusions

This review highlights the distinct physiological responses between DWR and TR, demonstrating that TR imposes greater cardiometabolic demands, as evidenced by higher VO_2max, heart rate, pulmonary ventilation, and blood lactate accumulation. These differences are primarily attributed to hydrostatic pressure, reduced activation of antigravity muscles, altered biomechanics, and enhanced thermoregulation in the aquatic environment. While TR is more effective for maximizing aerobic capacity, DWR presents a valuable low-impact alternative, particularly for individuals recovering from injuries, older adults, or those with obesity.

The key takeaway is that DWR should not be viewed as a direct substitute for TR but rather as a complementary modality with unique benefits. Given its reduced cardiovascular strain, exercise intensity in water should be prescribed using aquatic-specific parameters rather than extrapolating from land-based assessments. Future research should focus on standardizing protocols, investigating long-term training adaptations, and refining intensity prescription methods to fully optimize the application of DWR in both athletic and clinical settings.

References

Araujo, M. K. D., Baeza, R. M., Zalada, S. R. B., Alves, P. B. R., & Mattos, C. A. D. (2015). Injuries among amateur runners. Revista brasileira de ortopedia, 50, 537-540.

Azevedo, L. B., Lambert, M. I., Zogaib, P. S., & Barros Neto, T. L. (2010). Maximal and submaximal physiological responses to adaptation to deep water running. Journal of sports sciences, 28(4), 407-414.

Becker, B. E. (2009). Aquatic therapy: scientific foundations and clinical rehabilitation applications. Pm&r, 1(9), 859-872.

Brown, S. P., Chitwood, L. F., Beason, K. R., & McLemore, D. R. (1996). Perceptual responses to deep water running and treadmill exercise. Perceptual and motor skills, 83(1), 131-139.

Bushman, B. A. (2012). Deep-water running for aerobic fitness. ACSM's Health & Fitness Journal, 16(4), 4-7.

Butts, N. K., Tucker, M., & Greening, C. (1991). Physiologic responses to maximal treadmill and deep water running in men and women. The American Journal of Sports Medicine, 19(6), 612-614.

Chu, K. S., Rhodes, E. C., Taunton, J. E., & Martin, A. D. (2002). Maximal Physiological Responses to Deep-Water and Treadmill Running in Young and Older Women. Journal of Aging and Physical Activity, 10(3), 306-313. Retrieved Feb 27, 2025, from https://doi.org/10.1123/japa.10.3.306

Davidson, K., & McNaughton, L. (2000). Deep water running training and road running training improve VO2 max in untrained women. The Journal of Strength & Conditioning Research, 14(2), 191-195.

Dowzer, C. N., Reilly, T., Cable, N. T., & NEVILLE, A. (1999). Maximal physiological responses to deep and shallow water running. Ergonomics, 42(2), 275-281.

Eyestone, E. D., Fellingham, G., George, J., & Fisher, A. G. (1993). Effect of water running and cycling on maximum oxygen consumption and 2-mile run performance. The American Journal of Sports Medicine, 21(1), 41-44.

Frangolias, D. D., Rhodes, E. C., & Taunton, J. E. (1996). The effect of familiarity with deep water running on maximal oxygen consumption. The Journal of Strength & Conditioning Research, 10(4), 215-219.

Frangolias, D. D., & Rhodes, E. C. (1995). Maximal and ventilatory threshold responses to treadmill and water immersion running. Medicine and Science in Sports and Exercise, 27(7), 1007-1013.

Glass, R. A. (1989). Comparative biomechanical and physiological responses of suspended deep water running to hard surface running.

Hall, J. E., & Guyton, A. C. (2017). Guyton e Hall Perguntas e Respostas em Fisiologia. Elsevier Brasil.

Haffor, A. S., Mohler, J. G., & Harrison, A. C. (1991). Effects of water immersion on cardiac output of lean and fat male subjects at rest and during exercise. Aviation, space, and environmental medicine, 62(2), 123-127.

Herdy, A. H., & Caixeta, A. (2016). Brazilian cardiorespiratory fitness classification based on maximum oxygen consumption. Arquivos brasileiros de cardiologia, 106, 389-395.

Kanitz, A. C., Reichert, T., Liedtke, G. V., Pinto, S. S., Alberton, C. L., Antunes, A. H., ... & Kruel, L. F. M. (2015). Respostas cardiorrespiratórias máximas e no limiar anaeróbio da corrida em piscina funda. Revista Brasileira de Cineantropometria & Desempenho Humano, 17, 41-50.

Masumoto, K., Mefferd, K. C., Iyo, R., & Mercer, J. A. (2018). Muscle activity and physiological responses during running in water and on dry land at submaximal and maximal efforts. The Journal of Strength & Conditioning Research, 32(7), 1960-1967.

Mercer, J. A., & Jensen, R. L. (1997). Reliability and validity of a deep water running graded exercise test. Measurement in Physical Education and Exercise Science, 1(4), 213-222.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2016). Fisiologia do exercício. Grupo Gen-Guanabara Koogan.

Michaud, T.J., Brennan, D.K., Wilder, R.P., & Sherman, N.W. (1995). Aquarunning and Gains in Cardiorespiratory Fitness. Journal of Strength and Conditioning Research, 9, 78–84.

Moening, D., Scheidt, A., Shepardson, L., & Davies, G. J. (1993). Biomechanical comparison of water running and treadmill running. Isokinetics and exercise science, 3(4), 207-215.

Nakanishi, Y., Kimura, T., & Yokoo, Y. (1999). Physiological responses to maximal treadmill and deep water running in the young and the middle aged males. Applied Human Science, 18(3), 81-86.

Pereira, E. F. B. B., & Borges, A. C. (2006). Influência da corrida como exercício aeróbio na melhora do condicionamento cardiorespiratório. Revista Estudos-Revista de Ciências Ambientais e Saúde (EVS), 33(4), 573-588.

Peyré-Tartaruga, L. A., Tartaruga, M. P., Coertjens, M., Black, G. L., Oliveira, À. R., & Kruel, L. F. M. (2009). Physiologic and kinematical effects of water run training on running performance. International Journal of Aquatic Research and Education, 3(2), 5.

Kwok, M. M., So, B. C., Heywood, S., Lai, M. C., & Ng, S. S. (2022). Effectiveness of deep water running on improving cardiorespiratory fitness, physical function and quality of life: A systematic review. International journal of environmental research and public health, 19(15), 9434.

Risch, W. D., Koubenec, H. J., Beckmann, U., Lange, S., & Gauer, O. H. (1978). The effect of graded immersion on heart volume, central venous pressure, pulmonary blood distribution, and heart rate in man. Pflügers Archiv, 374, 115-118.

Rowell, L. B. (1993). Human cardiovascular control. Oxford University Press.

Svedenhag, J., & Seger, J. (1992). Running on land and in water: comparative exercise physiology. Medicine and science in sports and exercise, 24, 1155-1155.

da Silva, I. R. S., dos Santos Oliveira, L., de Freitas Berenguer, M., de Sousa, A. V. F., do Nascimento, J. A., & da Cunha Costa, M. (2010). Reprodutibilidade de um protocolo de esforço durante a corrida em piscina funda. Motricidade, 6(4), 47-54.

Tiggemann, C. L., Alberton, C. L., Posser, M. S., Bridi, J., & Kruel, L. F. M. (2007). Comparação de variáveis cardiorrespiratórias máximas entre a corrida em piscina funda e a corrida em esteira. Motriz Revista de Educação Física, 266-272.

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