The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review

Article *in* International Journal of Sports Physiology and Performance · December 2017

DOI: 10.1123/ijspp.2017-0327

3 authors:

Mark Kenneally
3 PUBLICATIONS 19 CITATIONS

Arturo Casado
King Juan Carlos University
26 PUBLICATIONS 75 CITATIONS

Jordan Santos-Concejero
Universidad del País Vasco / Euskal Herriko Unibertsitatea
63 PUBLICATIONS 727 CITATIONS

Note. This article will be published in a forthcoming issue of the *International Journal of Sports Physiology and Performance*. The article appears here in its accepted, peer-reviewed form, as it was provided by the submitting author. It has not been copyedited, proofread, or formatted by the publisher.

Section: Brief Review

Article Title: The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review

Authors: Mark Kenneally[1], Arturo Casado[2], and Jordan Santos-Concejero[1]

Affiliations: [1]Department of Physical Education and Sport. University of the Basque Country UPV/EHU (SPAIN). [2]Faculty of Health Sciences, Isabel I University (SPAIN).

Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: November 8, 2017

DOI: https://doi.org/10.1123/ijspp.2017-0327

"The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review" by Kenneally M, Casado A, Santos-Concejero J
International Journal of Sports Physiology and Performance

The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review

Mark Kenneally[1], Arturo Casado[2], Jordan Santos-Concejero[1]

[1]Department of Physical Education and Sport. University of the Basque Country UPV/EHU (SPAIN)
[2]Faculty of Health Sciences, Isabel I University (SPAIN)

Contact details:
Dr. Jordan Santos-Concejero, Department of Physical Education and Sport, Faculty of Physical Activity and Sport Sciences, University of the Basque Country UPV/EHU. Portal de Lasarte 71; 01007, Vitoria-Gasteiz, SPAIN.

E-mail: jordan.santos@ehu.eus Tel: +34 945013538
ORCID: 0000-0001-9467-525X

Preferred running head: Training intensity distribution in distance runners

Word Count (excluding references): 4213
Abstract Word Count: 226
References: 35
Number of figures and tables: 6 (4 Figures and 2 Tables)

"The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review" by Kenneally M, Casado A, Santos-Concejero J
International Journal of Sports Physiology and Performance

ABSTRACT

This review aimed to examine the current evidence for three primary training intensity distribution types; 1) Pyramidal Training, 2) Polarised Training and 3) Threshold Training. Where possible, we calculated training intensity zones relative to the goal race pace, rather than physiological or subjective variables. We searched 3 electronic databases in May 2017 (PubMed, Scopus, and Web of Science) for original research articles. After analysing 493 resultant original articles, studies were included if they met the following criteria: a) participants were middle- or long-distance runners; b) studies analysed training intensity distribution in the form of observational reports, case studies or interventions; c) studies were published in peer-reviewed journals and d) studies analysed training programs with a duration of 4 weeks or longer. Sixteen studies met the inclusion criteria, which included 6 observational reports, 3 case studies, 6 interventions and 1 review. According to the results of this analysis, pyramidal and polarised training are more effective than threshold training, although the latest is used by some of the best marathon runners in the world. Despite this apparent contradictory findings, this review presents evidence for the organisation of training into zones based on a percentage of goal race pace which allow for different periodisation types to be compatible. This approach requires further development to assess whether specific percentages above and below race pace are key to inducing optimal changes.

KEY WORDS: Polarised training, pyramidal training, threshold training, race pace, training program

INTRODUCTION

Endurance training involves manipulation of intensity, duration and frequency of training sessions[1]. The precise detail of this "manipulation", however, remains an area of debate across the literature. To further guide understanding of this area, different training intensity zones have been described, determined by either physiological factors: i.e. lactate threshold (LT), ventilatory thresholds (VT), percentage of the maximum oxygen uptake (%VO_{2max}), percentage of the maximum heart rate (%HR) or subjective factors: i.e. session goal or session rate of perceived exertion (RPE-Borg Scale)[2].

Three training intensity zones of endurance athletes are most commonly used in the literature[1,3], and are considered similar regardless of the method used to determine them. However, up to seven can be also used to describe the Training Intensity Distribution (TID)[4]. Both TID and periodisation of training volume and intensity are traditionally considered to be important factors in the design of a training program for endurance running performance[5].

There appears to be longstanding consensus in the literature regarding factors that limit such performance, namely vVO_{2max}[35], VO_{2max}[6], LT[6,7] and running economy[8], and on how these factors could be improved by using different training intensity procedures. However, a disparate number of TIDs are employed in practice[9]. Three primary TIDs are recognised in this review; (1) the traditional Pyramidal approach, in which decreasing volume of running is performed in zones 1, 2 and 3 respectively. Typically[32] this has been described as comprising 80% in Zone 1, with the remaining 20% split between zones 2 and 3, decreasing respectively; (2) Polarised Training, in which relatively high volumes of training are performed in zone 1(~80%) and zone 3 (20%), with little or none in zone 2[32] and (3) Threshold Training, in which higher volumes (>20%) of running are performed in zone 2 than other models[32]. Previous research has identified pyramidal training as the primary TID employed by well-trained and elite endurance athletes, noting that "some world-class athletes adopt a so-called 'polarized' TID during certain phases of the season "[3].

This observation has been supported by an observational review[10] detailing the training of international level distance runners, which notes the emphasis on relatively high volume-low intensity in the training of athletes specialising in distances from 1500m to marathon. However, a training manual published by the International Athletics Federation (IAAF) based on the work of Renato Canova (the coach of some of the fastest Kenyan marathon runners in recent times, including World Record holders) has demonstrated a tendency towards a threshold-oriented TID[11]. Seiler & Tonnessen[1] argue the case for an 80:20 distribution ratio between high-intensity and low-intensity work based on observational reports describing the training of elite endurance athletes. These authors recognise both pyramidal and polarised models of TID as being most common in these athletes[1].

It is against this apparently contradictory background that this review intends to examine the current literature specifically for endurance running, and subsequently to analyse the available data, where possible, by determining intensity zones relative to the goal race pace in different distances, rather than physiological or subjective variables.

METHODS

Experimental Approach to the Problem

A literature search was conducted on May 6, 2017. The following databases were searched: PubMed, Scopus, and Web of Science. Databases were searched from inception up to May 2017, with no language limitation. Citations from scientific conferences were excluded.

Literature Search

In each database the title, abstract and keywords search fields were searched. The following keywords, combined with Boolean operators (AND, OR) were used: "training intensity distribution running", "periodisation running", "training intensity distribution endurance", "periodisation endurance", "polarised training running", "pyramidal training running", and "threshold training running". No additional filters or search limitations were used.

Inclusion Criteria

Studies were eligible for further analysis if the following inclusion criteria were met; a) participants were middle- or long-distance runners (studies with triathletes or any other kind of athletes were excluded); b) studies analysed training intensity distribution and/or periodisation in the form of observational reports, case studies or interventions; c) studies were published in peer-reviewed journals and d) studies analysed training programs with a duration of 4 weeks or longer.

Two independent observers reviewed the studies and then individually decided whether inclusion was appropriate. In the event of a disagreement, a third observer was consulted to determine the inclusion of the study. A flow chart of the search strategy and study selection is shown in Figure 1.

Quality assessment

Oxford's level of evidence[12] and the Physiotherapy Evidence Database (PEDro) scale[13] were used by 2 independent observers in order to assess the methodological quality of the articles included in the review. Oxford's level of evidence ranges from 1a to 5, with 1a being systematic reviews of high-quality randomised controlled trials (RCT) and 5 being expert opinions. The PEDro scale consists of 11 different items related to scientific rigor. The items include random allocation; concealment of allocation; comparability of groups at baseline; blinding of subjects, researchers and assessors; analysis by intention to treat; and adequacy of follow-up. Items 2-11 can be rated with 0 or 1, so the highest rate in the PEDro scale is 10, and the lowest, 0. Zero points are awarded to a study that fails to satisfy any of the included items, and 10 points to a study that satisfies all the included items.

STATISTICAL ANALYSIS

All values are expressed as mean ± standard deviation (SD). In studies with sufficient data, TID determined by traditional physiological parameters was compared to a race-pace based TID using a Cohen *d*[14]. Training zones for the race-pace approach were determined as following; zone 1: volume performed at <95% of goal race pace, zone 2; volume performed between 95% and 105% of goal race pace, and zone 3; volume performed at >105% of goal race pace. The magnitude of differences, or effect size (ES) of this comparison was interpreted as small (>0.2 and <0.6), moderate (>0.2 and <0.6), moderate (≥0.6 and <1.2), large (≥1.2 and <2) and very large (≥2.0) according to the scale proposed by Hopkins et al.[15]

RESULTS

Studies Selected

The search strategy yielded 493 total citations as presented in Figure 1. After removing 163 duplicates and reviewing the resultant 330 full-text articles, 16 studies met the inclusion criteria. Excluded studies had at least one of the following characteristics: participants were not middle- or long-distance runners, intervention/observation period lasted less than 4 weeks. The overall sample included 6 observational reports, 3 case studies and 6 interventions. 1 review was also included (Table 1)

Level of Evidence and Quality of the Studies

Four of the 16 included studies had a level of evidence 1c (high-quality RCT). The 12 remaining studies had a level of evidence of 2c or less as participants were not randomly allocated into the intervention or control groups. Also, mean score in the PEDro scale was 3.75 ± 1.9, with values ranging from 1 to 6 (Table 2).

Characteristics of the Participants

Participants were characterised as recreational or high-level athletes, with delineation defined by whether the athletes competed internationally. A summary of participants' characteristics is presented in Table 1. The total number of participants was 215 (194 men and 21 women) with an age ranging from 17 to 51 years.

Evidence for a Pyramidal Training Intensity Distribution

Four interventional studies exist which support the use of a pyramidal TID; Esteve-Lanao et al.[16], Clemente-Suarez & Gonzalez-Rave[17], Manzi et al.[18], and Clemente-Suarez et al.[19]. Similarly, 4 observational reports[4,20,21,22] and 2 case studies[23,24] confirm the use of pyramidal training in elite and well-trained runners

Esteve-Lanao et al.[16] examined the effect of decreasing volume of training performed at threshold intensity on running performance in 12 male sub-elite endurance runners, while maintaining equal volumes of high-intensity work between 2 groups (Threshold & Pyramidal training groups; Figure 2). Running performance was assessed by a simulated 10.4-km XC race assessed before and after the 5 month intervention period. The *Pyramidal* group displayed a significantly better improvement in performance than the *Threshold* group. The TID in both *Threshold* (Figure 2A) and *Pyramidal* groups (Figure 2B) was different from a race-pace based TID (Figure 2; ES>2.0, very large effect). It should be noted that zone 3 can only be considered a sub-set of zone 2 in this analysis as details of the zone 3 training are not provided but are equal between groups.

Clemente-Suarez and Gonzalez-Rave[17], examined the effect of applying a pyramidal TID over a 4 week time period to 30 recreational athletes. One group (*constant*) maintained a constant weekly training load in terms of volume and intensity, while another group had an increasing proportion of higher intensity work, week by week over the 4 weeks. A final group were free to train as they wished. Total training volume for the 4 weeks was recorded by time (minutes). The constant group completed 1051 ± 11 minutes, the increasing group completed 1105 ± 1.3 minutes and the free group completed 1512 ± 67.6 minutes. The stated goal of the 4 week time period was to develop "aerobic endurance". No race distance or performance was specified, rather the changes were measured via laboratory testing. No significant performance differences existed between groups post-study, although the groups did exhibit different physiological changes over the 4 weeks. Clemente-Suarez et al.[19], using data from the aforementioned study, found that the group with increasing intensity over the 4 weeks had a significantly better running velocity at 8 $mmol·L^{-1}$ at mid- and post-condition. No time-trial or race performance data for the groups were provided so it was not possible to examine the TIDs in this method.

Manzi et al.[18] assessed the TID of 7 recreational marathon runners in the preparation phase of a marathon training cycle. Interestingly, when their training (which was pyramidal in nature according to their baseline physiological testing) was assessed against their eventual race pace, it appeared to be a polarised type TID (Figure 3; ES>2.0, very large effect).

Robinson et al.[20] analysed 13 national ranked male New Zealand distance runners' training during the "build-up" phase of their season and identified 2 training zones according to blood lactacte: above LT (4 $mmol·L^{-1}$) or below LT. Training during this period was described as 96% below LT and 4% above LT.

Tjelta and Enoksen[21] described the training of a group of 4 top-level male Junior cross-country (XC) runners over the course of a season. Five training zones based on HR and blood lactate were used to describe the TID and training was divided into 3 seasons; Base, Track and XC. The training in this study can be described as traditionally pyramidal in distribution, with 78%, 81%, and 78% of the training volume having been carried out in the low-intensity zone

1 in Base, Track and XC seasons, respectively. Race intensity for these athletes across the whole season was zone 3 (10-km and 3-km), with some zone 4 (1500 m) races during the Track season. Training intensification (training phases closer to competition) is characterised by an increase in the volume just below, up to and over race pace (zones 3 and 4). In this study, when TID was calculated according to race pace, the volume of training performed above race pace was similar to other studies using either pyramidal or polarised methods[4,24,18,27].

Enoksen et al.[4] analysed 6 top international Norwegian marathon and track distance runners' training in a subsequent study. 7 training zones were identified and used the determine TIDs. The marathon runners performed a relatively high proportion of their training at zone 2 (equivalent of marathon pace) and zone 4 (10-km pace) in their Base and Pre-competition phase with nothing at zone 3 (half-marathon pace), and then in competition phase, nothing at zone 4 and an increase in the volume at zone 3, while maintaining a relatively high proportion at zone 2. The track runners (who competed over 5-km) completed relatively high volumes at zones 2 and 3 in all phases. However, the volume in zone 3 dropped in the competition phase and zone 5 (3-km and 5-km race pace) volume increased. They had minimal volume in zone 4 (10-km pace) across all phases.

Esteve-Lanao et al.[22] described the training of 8 regional and National class Spanish runners, using 3 intensity zones; up to VT_1, between VT_1 and VT_2, and above VT_2, and similarly described a pyramidal distribution (71% in zone 1, 21% in zone 2, 8% in zone 3).

Tjelta[23] analysed the training of the 2012 European 1500m champion over 4 years, and noted a pyramidal distribution over the time period, at all times of the season despite some variation corresponding to the periodisation of the athletes training. Five intensity zones were described relative to blood lactate, $\%HR_{max}$, and intended physiological adaptation, and during all phases of training the maintenance of a relatively high volume in zone 2 (threshold training) was observed. This does reduce closer to competitive season but still constitutes a larger proportion of training than zone 3, 4, or 5 at all time-points.

Similarly, the training of 9 times New York marathon winner Grete Waitz was also reported as pyramidal at all time points across a 2 year time period[24]. The periodisation identified 7 intensity zones and a decreasing volume of work done at increasing intensity levels was observed.

Evidence for a Polarised Training Intensity Distribution

Two interventional studies exist which support the use of a polarised TID: Muñoz et al.[25], and Stoggl & Sperlich[3]. Both studies defined 3 intensity zones relative to physiological characteristics. Similarly, 3 observational reports[26,27,28] and 1 case study[29] confirm the use of polarised training in elite, well-trained and recreational athletes.

Muñoz et al.[25] quantified the impact of TID on 10-km race performance in 30 recreational athletes. Two groups, emphasising polarised or threshold type training were examined. Both groups improved over a 10-week intervention period; although the *Polarised* group exhibited a better improvement over 10-km race distance than the *Threshold* group (5.0% *vs.* 3.6%, non-significant). Both groups completed an 8-week standard training program prior to the study, which was pyramidal in TID. In this study, both groups spent the same absolute amount of time in zone 3 with the polarised group zone 1 (Figure 4A) and the threshold group emphasising zone 2 (Figure 4B). The actual completed training of the polarised group was not a truly polarised TID as the authors intended that this group would complete only 5.0% of the training in Zone 2, rather than the 13.5% finally completed. The TID in both *Polarised* (Figure 4A) and *Threshold* groups (Figure 4B) was different from a race-pace based TID (Figure 4; ES>2.0, very large effect).

Stoggl & Sperlich[3] examined 48 athletes, 21 of whom were national-level runners, in their RCT comparing 4 different TIDs over a 9 week period. The TIDs were: High-Volume, Threshold, High Intensity Interval Training and Polarised. Polarised training resulted in the greatest improvement of the variables examined ($\dot{V}O_{2max}$, peak velocity and time to exhaustion on a ramp protocol). A time-trial or race performance was not performed to allow analysis of race-pace zones based on this.

Billat et al.[26] compared top class male Portuguese and French marathon runners to their "high-level" counterparts (as defined by a marathon time of 2:12). They described high-volumes of polarised training. Their zones were defined, however, by marathon race pace. zone 1 was described as <marathon pace (MP), zone 2 = MP, zone 3 >MP, a definition not replicated anywhere else in the literature and no specification of the tolerance around marathon pace for each zone is provided. The same authors also described the training of Kenyan distance runners (10-km specialists), and described 2 main TID types[27]: high-volume low-intensity and low-volume high-intensity. In the group studied there were 13 males (6 high-intensity type and 7 low-intensity type) and 7 females (6 high-intensity type and 1 high-intensity type). The lower volume athletes in this study tended to perform more of their training in zones 4 and 5 (4.3 and 5.0% respectively) than their high-volume counterparts, who only performed 1.4% of their volume in zones 4 and 5 combined, with 14.4% in zone 3.

Stellingwerff[28] described the training of 3 Canadian international marathon runners over a 16 week period before a marathon race. The intensity zones were defined subjectively by RPE as: zone 1 (easy to somewhat hard); zone 2 ("Threshold"); and zone 3 (very hard to maximal). A polarised distribution was described in which 74%, 11% and 15% of training sessions were performed in Zones 1, 2, and 3, respectively.

Ingham[29] presented the case study of an international 1500m runner, who improved his personal best from 3:38.9 to 3:32.4 over a 2 two year period. The analysis of his training showed a reduction in training volume performed between 80-90% VO_{2max} from 42% to 20% and between 90-100% from 20 to 10%. At the same time, low-intensity training volume (<80% VO_{2max} increased from 20% to 55% and training volume at 100-130% VO_{2max} increased from 7% to 10%, thus emphasising a shift towards a more polarised TID. Note that these numbers are approximate as the information is only provided graphically in the article, and that 1500m race falls at approximately 110% VO_{2max}.

DISCUSSION

According to the results of this review, there is a clear dichotomous evidence base with regard to TID in the literature. The overwhelming evidence describes 2 main strands: Pyramidal and Polarised training.

Contemporary endurance training has developed, from a historical perspective from coaches such as Arthur Lydiard, who used pyramidal TIDs to coach successful athletes[10]. The more recent move towards Polarised type TIDs has emerged as scientific evaluation of endurance performance has identified key determinants of endurance performance, and methods by which to improve these determinants[30]. However, the precise nature of the interaction of these determinants and the effect of that interaction remains elusive.

For example, although LT is recognised as one of the key determinants of endurance performance[7], threshold type training is considered to be more demanding than other TIDs (i.e. pyramidal and polarised), potentially because of effects on the autonomic and endocrine systems, or on the lactate/power profile[25]. When threshold training has been compared in this regard in the literature, it consistently proves to be less effective in the studies available. Yet, there is anecdotal evidence, at the very highest level, of the use of threshold training to great effect in structuring world best marathon performance.

The coach of a number of world class Kenyan athletes has written a marathon training manual for the International Athletics Federation (IAAF)[11], and has made publicly available the training programmes of his athletes. These programmes repeatedly show the use of high volumes (i.e. differeing from the traditional 80:20 approach) of training in the threshold zone (as defined by %$V\text{O}_{2\text{max}}$, assuming 100% of $V\text{O}_{2\text{max}}$ corresponds to approximately 3000m pace). The coach (Renato Canova) describes this training as specific race pace.

The periodisation employed, however, demonstrates an initial block of polarised training, emphasising high and low intensity, leading into a specific preparatory phase, which is threshold-oriented, thereby employing both of the main TIDs described at different phases of training, according to the intended goal of the phase[11]. So in the specific example, marathon pace lies in the threshold zone, so a relatively large volume of training is performed in this physiological zone as the date of a specific race approaches. The volume of training performed around race pace seems to be dictated by the distance of the impending race, with shorter races, requiring faster paces, seeing less volume, and longer races requiring increasing volumes in around race pace.

Thus, the dichotomous approach described above may be flawed in its inception. It may prove more valuable in future studies to examine the precise physiological characteristics associated with optimal race performance, and how these physiological characteristics change with different TID approaches. Similarly, different approaches may prove valuable at different phases and for approaching different races[25]. In this way, the training may be organised in the early parts according to physiological characteristics such as HR or lactate profile, but as the race date approaches, becomes more pragmatic and focuses on running at and around specific race pace, regardless of what is happening to physiological measurables[21,24]. This represents a way of incorporating the scientific principles which are fairly well established as being important for specific race distance performance, while also being cognisant of the fact that the literature is deficient in describing an optimal TID and periodisation strategy, based on good evidence[10].

It is well established that from races as short as 1500m, the aerobic system is the main contributor of energy (85%)[31] so the TIDs seen reflect that, as no matter what TID is examined zone 1 is always the highest proportion. However, when comparing physiological-based intensity zones and race pace-based intensity zones it seems from the data assessed in this review that race pace may be a larger factor in the design of training programmes than physiological variables. This may be a coaching flaw, but the interesting similarity in the TIDs when analysed by a race pace based approach at least warrants some attention as these are data from successful athletes. As discussed above, no optimal TID has been well established, and similarly no optimal numbers for the physiological determinants (v$\dot{V}O_{2max}$, $\dot{V}O_{2max}$, Running economy and LT) of middle and long distance running to predict performance exist[2]. The interaction between these variables is the key to endurance running and it may be possible that race pace based training provides the perfect stimulus for their concurrent development. As already described above, training aimed at improving threshold seems to limit the development of $\dot{V}O_{2max}$[3]. However, as Coyle & Krauenbuhl[6] showed, large variation in laboratory endurance performance is explained by the %$\dot{V}O_{2max}$ which can be utilised at threshold so this limitation may not be a hindrance to performance. The specificity of intention may be more important.

Race pace based zones may also reflect the fact that races in endurance running competition are directly comparable because of the similarity of courses and the validity of time comparison on different courses. Other endurance sports, such as road cycling, rowing or XC skiing, which have been examined in the literature on TID[32,33] do not share this same capacity for direct competition to competition comparison of speed, because of the nature of different courses characteristics (i.e. profile, altitude...). Training organised, therefore, based on physiological characteristics for these sports is the norm. No study in these sports, to the authors’ best knowledge, has reported a polarised TID based on zones that are externally defined (i.e. power or speed).

This dichotomy between measuring and monitoring workload internally (physiologically guided) *vs*. externally (e.g. pace guided) has been explored in 2 recent reviews: Foster et al.[34] and Mujika[30]. Foster et al.[34] outline the practical difficulties of accurately monitoring internal workload/physiological parameters, which they note are lessening. Nonetheless such practical difficulties should not affect the development of theoretical principles based on physiological measures (e.g. Running economy, VO_{2max} and LT) should an integrated approach to their concurrent development become evident.

Further studies looking at the behaviour of physiological characteristics such as HR response, top speed and lactate profile at different phases of a season, and also how they change, in the short and medium term in response to training are thus warranted. Comparison of these measures to race performance, along with physiological profiling compared to performance, may also allow better understanding of the interactions between physiological characteristics, and the impact of these interactions on performance. This may allow for better individualised planning and prescription of training, which is founded on evidence rather than anecdote/tradition.

Conclusions

Current evidence describes pyramidal and polarised training as more effective than threshold training, although the latest is used by some of the best marathon and distance runners in the world. Despite the apparent contradictory evidence on TID and periodisation, an approach based on race pace has been suggested in this review which may allow for different TID types to be compatible. It is suggested that this may be unique to endurance running because of the standardisation of race distances and courses. A race pace based TID recognises the traditional high volume of low intensity training associated with endurance training, but presents evidence (when analysed retrospectively) for the organisation of high intensity training into zones based on a percentage of race pace, rather than physiological zones, which appears to be relatively consistent across distances. A training session at a given percentage of race pace for a longer event is naturally going to be slower, in absolute terms, than a session at the same percentage of race pace for a middle distance event. Therefore these 2 sessions may fall into completely different physiological zones yet may serve the same purpose from a session intention perspective. The requirement to sustain a particular pace obviously also differs by race distance, and in this way the volume of these sessions will also differ-longer races requiring longer sessions etc, which may also affect analysis via a physiological-only approach. Tjelta et al.[21,24] recognise the relationship between race pace and physiology and display race pace alongside physiological zones as a secondary zone target. This approach requires further development to assess whether specific percentages above and below race pace are key to inducing optimal changes, and whether, as has been questioned above, the potential concurrent development of relevant physiological characteristics is indeed a factor. Such an approach throws more questions about the nature of endurance running performance, but may help to guide experimental enquiries into this performance along a slightly different path than currently being tread.

REFERENCES

1. Seiler S, Tonnessen E. Intervals, threshold and long slow distance: the role of intensity and duration in endurance training. *SportsScience*. 2009;13:32-53.

2. Seiler S, Kjerland, GO. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? *Scand J Med Sci Sports.* 2006;16:49-56.

3. Stoggl TL, Sperlich B. The training intensity distribution among well-trained and elite endurance athletes. *Frontiers Physiol* 2015;6:295.

4. Enoksen E, Tjelta AR, Tjelta LI. Distribution of training volume and intensity of elite male and female track and marathon runners. *Int J Sports Sci Coach* 2011;6: 273-293.

5. Faulkner JA. New perspectives in training for maximum performance. *JAMA* 1968*;*205:741-746.

6. Coyle EF. Integration of the physiological factors determining endurance performance ability. *Exerc Sports Sci Rev* 1995;13:25-63.

7. Allen WK, Seals DR, Hurley BF, Ehsani AA, Hagberg JM. Lactate threshold and distance running performance in young and older endurance athletes. *J Appl Physiol* 1985;58:1281-1284.

8. Conley DL, Krauenbuhl, GS. Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc 1980;12:357-360.

9. Stoggl TL, Sperlich B. Polarised training has greater impact on key endurance variables than threshold, high intensity, or high volume training. *Frontiers Physiol* 2014*;*5:33.

10. Tjelta LI. The training of international level distance runners. *Int J Sports Sci Coach* 2016;11:122-134.

11. Arcelli E, Canova R. *Scientific training for the Marathon.* Monaco: International Association of Athletics Federation; 1999

12. Oxford Centre for Evidence-based Medicine. *Levels of Evidence*. Univ Oxford. 4–5, 2009.

13. de Morton, NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother* 2009;55:129–33.

14. Cohen J. *Statistical power analysis for the behavioral sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

15. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41:3-13.

16. Esteve-Lanao J, Foster C, Seiler S, Lucia A. Impact of training intensity distribution on performance in endurance athletes. *J Strength Cond Res* 2007;21:943-949.

17. Clemente-Suarez VJ, Gonzalez-Rave JM. Four weeks of training with different aerobic workload distributions-effect on aerobic performance. *Eur J Sports Sci* 2014;14:S1-S7.

18. Manzi V, Bovanzi A, Castagna C, Sinibaldi Salimei P, Volterrani M, Iellamo F. Training-load distribution in endurance runners: Objective versus subjective assessment. *Int J Sports Physiol Perform* 2015;10:1023-1028.

19. Clemente-Suarez VJ, Dalamitros AA, Nikolaidis PT. The effect of a short term training period on physiological parameters and running performance: intensity distribution vs constant intensity exercise. *J Sports Med Phys Fitness*. (Epub ahead of print), 2016.

20. Robinson DM, Robinson SM, Hume PA, Hopkins WG. Training intensity of elite male distance runners. *Med Sci Sports Exerc* 1991;23:1078-1082.

21. Tjelta LI, Enoksen, E. Training characteristics of male junior cross country and track runners on European top level. *Int J Sports Sci Coach* 2010;5:193-203.

22. Esteve-Lanao J, San Juan AF, Earnest CP, Foster C, Lucia A. How do endurance runners actually train? Relationship with competition performance. *Med Sci Sports Exerc* 2005;37:496-504.

23. Tjelta LI. A longitudinal case study of the training of the 2012 European 1500m track champion. *Int J Appl Sports Sci* 2013;25:11-18.

24. Tjelta LI, Tonnessen E, Enoksen E. A case study of the training of nine times New York Marathon winner Grete Waitz. *Int J Sports Sci Coach* 2014;9:139-157.

25. Muñoz I, Seiler S, Larumbe E, Esteve J. Does polarized training improve performance in recreational runners. *Int J Sports Physiol Perform* 2014;9:265-272.

26. Billat V, Demarle A, Slawinski J, Paiva M, Koralsztein JP. Physical and training characteristics of top-class marathon runners. *Med Sci Sports Exerc* 2001;33:2089-2097.

27. Billat V, Lepretre PM, Heugas AM, Laurence MH, Salim D, Koralsztein JP. Training and bioenergetic characteristics in elite male and female Kenyan runners. *Med Sci Sports Exerc* 2003;31:156-163.

28. Stellingwerff T. Case Study: Nutrition and training periodization in three elite marathon runners. *Int J Sport Nutr Exerc Metab* 2012;22:392-400.

29. Ingham S. Training distribution, physiological profile, and performance for a male international 1500m runner. *Int J Sports Physiol Perform* 2012;7:193-195.

30. Mujika I. Quantification of training and competition loads in endurance sports: methods and applications. *Int J Sports Physiol Perform* 2017;12:9-17.

31. Weyand P, Cureton K, Conely D, Sloniger M. Percentage anaerobic energy utilized during track running events. *Med Sci Sports Exerc* 1993;25:S105.

32. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes. *Int J Sports Physiol Perform* 2010;5:276-291.

33. Fiskerstrand A, Seiler S. Training and performance characteristics among Norwegian international rowers 1970-2001. *Scand J Med Sci Sports* 2004;14:303-310.

34. Foster C, Rodriguez-Marroyo JA, de Koning JJ. Monitoring training loads: the past, the present, and the future. *Int J Sports Physiol Perform* 2017;12:2-8.

35. McLaughlin JE, Howley ET, Bassett DR, Thompson DL, Fitzhugh EC. Test of the classic model for predicting endurance running performance. *Med Sci Sports Exerc* 2010; 42(5);991-997.

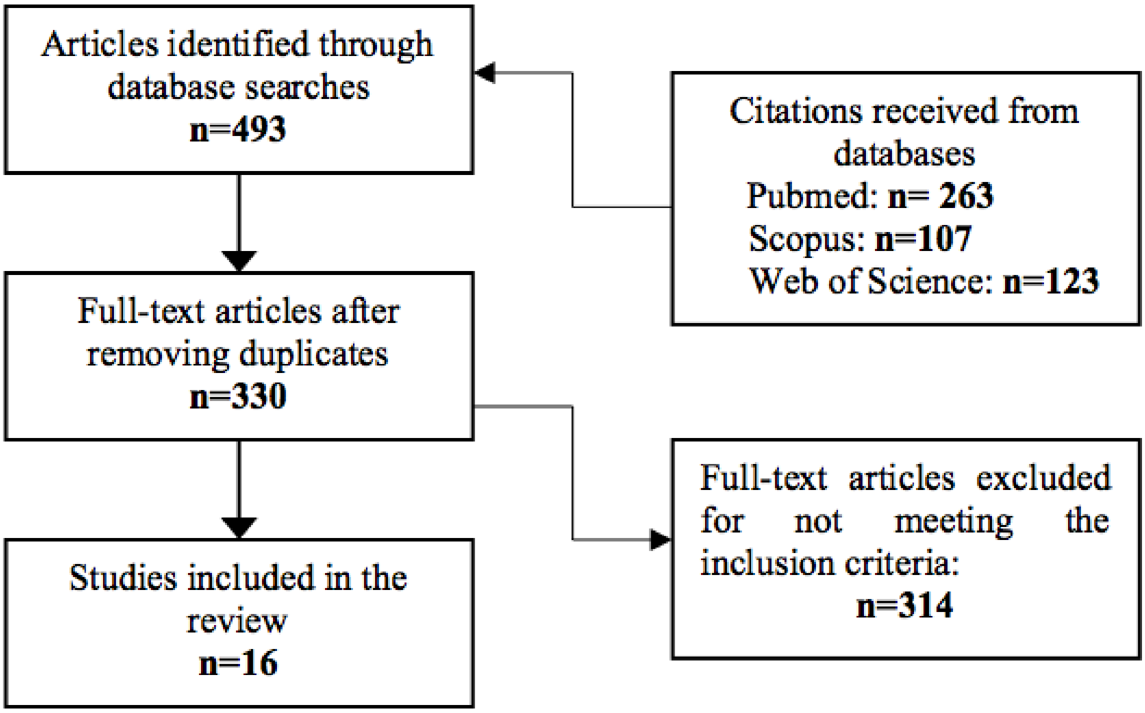

Figure 1. Flow chart of search strategy and selection of articles.

"The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review" by Kenneally M, Casado A, Santos-Concejero J
International Journal of Sports Physiology and Performance

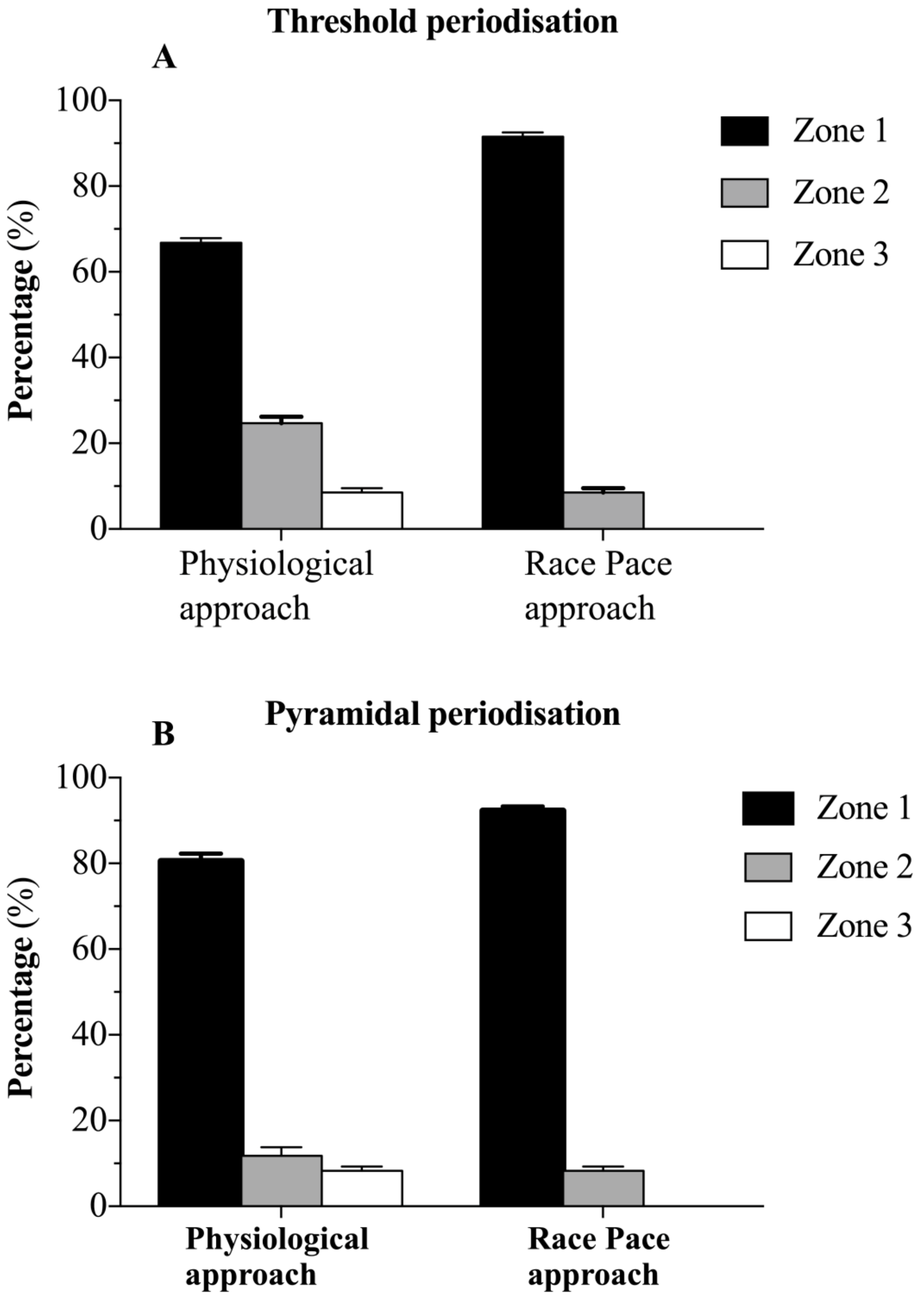

Figure 2. Training Intensity Distribution comparison between a physiological and a race pace based approached in a Threshold periodisation (A) and a Pyramidal periodisation (B) groups. Data from Esteve-Lanao et al. (2007).

"The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review" by Kenneally M, Casado A, Santos-Concejero J
International Journal of Sports Physiology and Performance

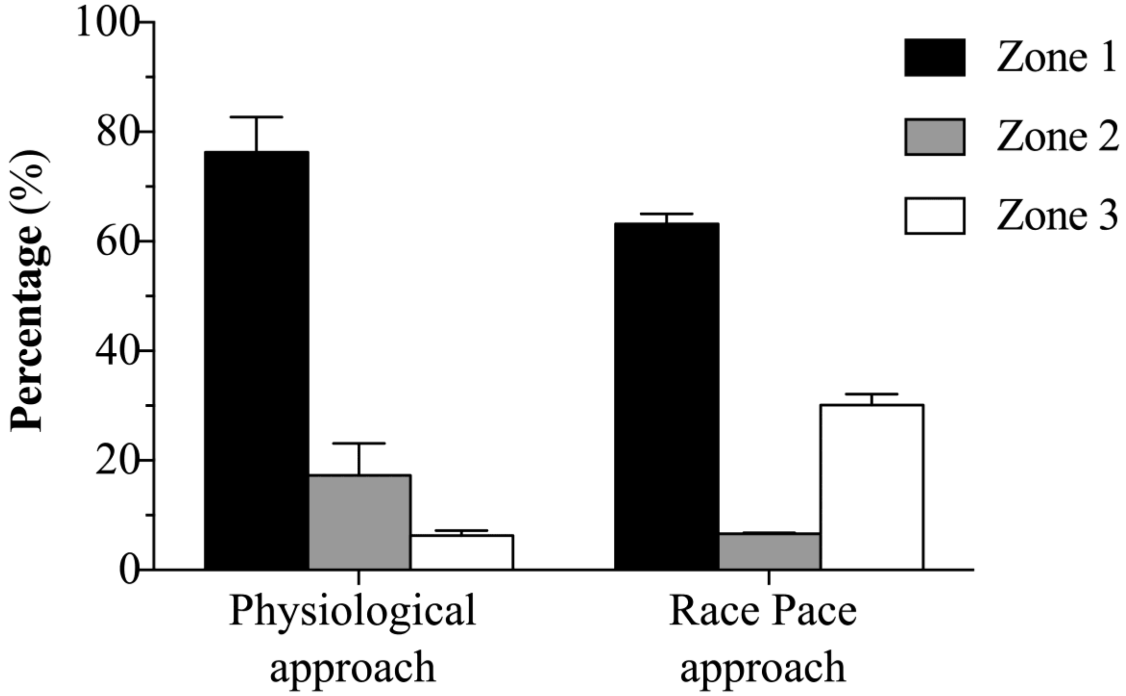

Figure 3. Training Intensity Distribution comparison between a physiological and a race pace based approached in a Pyramidal periodisation group. Training zones for the physiological approach were described as following: Zone 1) <2 mmol·L^{-1} of lactate; Zone 2) between 2 and 4 mmol·L^{-1} of lactate; Zone 3) > 4mmol·L^{-1} of lactate. Data from Manzi et al. (2015).

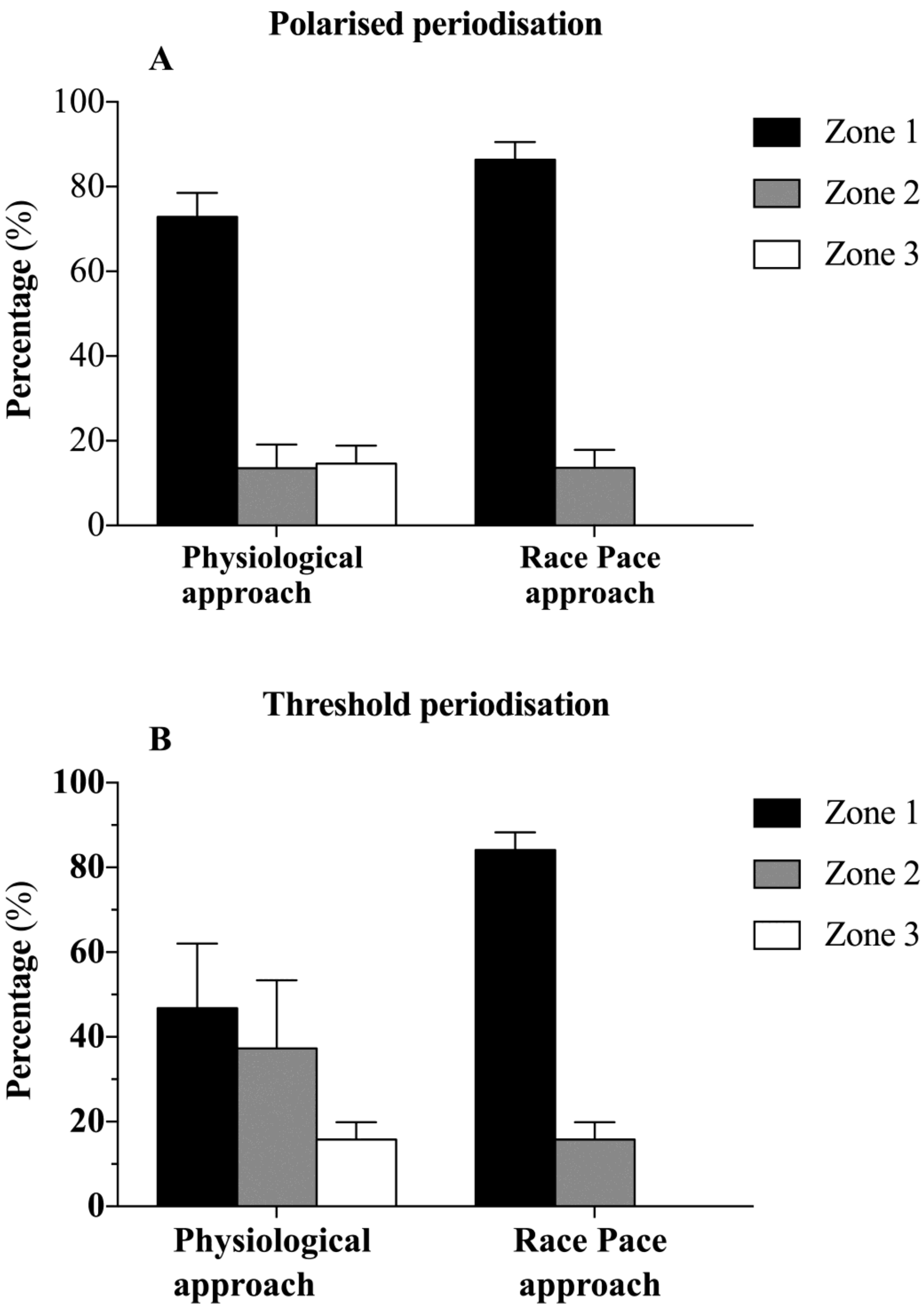

Figure 4. Training Intensity Distribution comparison between a physiological and a race pace based approach in a Polarised periodisation (A) and a Threshold periodisation (B) groups. Training zones for the physiological approach were described as following: Zone 1) <Ventilatory threhold (VT); Zone 2) between VT and the Respiratory Compensation Point (RCP); Zone 3) > RCP. Data from Muñoz et al. (2014).

"The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review" by Kenneally M, Casado A, Santos-Concejero J
International Journal of Sports Physiology and Performance

Table 1: Characteristics of the studies and the participants.

	Participants		Study	
Study	Number (M/F)	Age	Level	Main Outcome
Robinson et al. (1991)	13 (13/0)	26.1 ± 4.7	Elite	TID
Billat et al. (2001)	20 (10/10)	-	Elite	Physiology
Billat et al. (2003)	20 (13/7)	-	Elite	TID
Esteve-Lanao et al. (2005)	8 (8/0)	23 ± 2	Well-trained	TID
Esteve-Lanao et al. (2007)	20 (20/0)	27 ± 2	Well-trained	Race Performance
Tjelta & Enoksen (2010)	4 (4/0)	17.8 ± 1	Elite	TID & Race Performance
Enoksen et al. (2011)	6 (3/3)	Not specified	Elite	TID & Race Performance
Stellingwerff (2012)	3 (3/0)	28.3 ± 2.3	Elite	TID
Ingham (2012)	1 (M)	26	Elite	TID & Race Performance
Tjelta (2013)	1 (M)	20-21	Elite	TID & Race Performance
Stoggl & Sperlich (2014)	21 (not specified)	31 ± 6	Well-trained	Physiology
Muñoz et al. (2014)	30 (not specified)	34 ± 9	Recreational	Race Performance
Tjelta et al. (2014)	1 (F)	25/26	Elite	TID
Clemente-Suarez & Gonzalez-Rave (2014)	30 (30/0)	38.7 ± 9.8	Well-trained	Aerobic Performance
Manzi et al. (2015)	7 (7/0)	36.5 ± 3.8	Recreational	TID & Race Performance
Clemente-Suarez et al. (2016)	30 (30/0)	38.7 ± 9.8	Recreational	Physiology & performance
Tjelta (2016)	56 (34/22)	Not specified	Elite	TID

M/F = male/female; TID, training intensity distribution.

"The Effect of Periodisation and Training Intensity Distribution on Middle- and Long-Distance Running Performance: A Systematic Review" by Kenneally M, Casado A, Santos-Concejero J
International Journal of Sports Physiology and Performance

Table 2: Physiotherapy Evidence Database (PEDro) ratings and Oxford evidence levels of the included studies.

Study	PEDro ratings*												Evidence level
	1	2	3	4	5	6	7	8	9	10	11	**Total**	
Robinson et al. (1991)	No	0	0	0	0	0	0	1	0	0	0	1	4
Billat et al. (2001)	Yes	0	0	1	0	0	0	1	1	0	1	4	4
Billat et al. (2003)	Yes	0	0	1	0	0	0	1	1	1	1	5	4
Esteve-Lanao et al. (2007)	Yes	1	0	1	0	0	0	1	1	1	1	6	4
Tjelta & Enoksen (2010)	No	0	0	0	0	0	0	0	1	1	0	2	4
Enoksen et al. (2011)	No	0	0	1	0	0	0	0	0	0	0	1	4
Stellingwerff (2012)	No	0	0	1	0	0	0	0	0	1	1	3	4
Ingham (2012)	No	0	0	1	0	0	0	0	0	1	1	3	3b
Tjelta (2013)	No	0	0	0	0	0	0	0	1	1	0	2	4
Stoggl & Sperlich (2014)	Yes	1	0	1	0	0	0	1	1	1	1	6	1c
Muñoz et al. (2014)	Yes	1	0	1	0	0	0	1	1	1	1	6	1c
Tjelta et al. (2014)	No	0	0	0	0	0	0	0	1	1	0	2	4
Clemente-Suarez & Gonzalez-Rave (2014)	Yes	1	0	1	0	0	0	1	1	1	1	6	1c
Manzi et al. (2015)	Yes	0	0	1	0	0	0	1	1	1	1	5	2c
Clemente-Suarez et al. (2016)	Yes	1	0	1	0	0	0	1	1	1	1	6	1c
Tjelta (2016)	No	0	0	0	0	0	0	0	1	1	0	2	3a

Items in the PEDro scale: 1 = eligibility criteria were specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = blinding of all subjects; 6 = blinding of all therapists who administered the therapy; 7 = blinding of all assessors who measured at least 1 key outcome; 8 = measures of 1 key outcome were obtained from 85% of subjects initially allocated to groups; 9 = all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least 1 key outcome were analyzed by "intention to treat"; 10 = the results of between-group statistical comparisons are reported for at least 1 key outcome; 11 = the study provides both point measures and measures of variability for at least 1 key outcome.