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Research

Walking training with cueing of cadence improves walking speed and stride length after stroke more than walking training alone: a systematic review

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KEYWORDS

Stroke
Cue
Gait
Systematic review
Meta-analysis

CrossMark

ABSTRACT

Question: After stroke, is walking training with cueing of cadence superior to walking training alone in improving walking speed, stride length, cadence and symmetry? **Design:** Systematic review with meta-analysis of randomised or controlled trials. **Participants:** Adults who have had a stroke. **Intervention:** Walking training with cueing of cadence. **Outcome measures:** Four walking outcomes were of interest: walking speed, stride length, cadence and symmetry. **Results:** This review included seven trials involving 211 participants. Because one trial caused substantial statistical heterogeneity, meta-analyses were conducted with and without this trial. Walking training with cueing of cadence improved walking speed by 0.23 m/s (95% CI 0.18 to 0.27, I^2 = 0%), stride length by 0.21 m (95% CI 0.14 to 0.28, I^2 = 18%), cadence by 19 steps/minute (95% CI 14 to 23, I^2 = 40%), and symmetry by 15% (95% CI 3 to 26, random effects) more than walking training alone. **Conclusions:** This review provides evidence that walking training with cueing of cadence improves walking speed and stride length more than walking training alone. It may also produce benefits in terms of cadence and symmetry of walking. The evidence appears strong enough to recommend the addition of 30 minutes of cueing of cadence to walking training, four times a week for 4 weeks, in order to improve walking in moderately disabled individuals with stroke. **Review Registration:** PROSPERO (CRD42013005873). **[Nascimento LR, de Oliveira CQ, Ada L, Michaelsen SM, Teixeira-Salmela LF (2015) Walking training with cueing of cadence improves walking speed and stride length after stroke more than walking training alone: a systematic review. *Journal of Physiotherapy* 61: 10–15]**

Introduction

Recent data indicates that over 30 million people in the world have experienced and survived stroke.[1] Despite recent advances in medical and rehabilitation sciences, many individuals have residual walking disability after stroke, which has long-lasting implications for quality of life and ability to participate in activities of daily living.[2,3] If walking performance is poor after stroke, community activity may be limited and people may become housebound and isolated from society.[4,5] One of the main aims of rehabilitation is to enhance community ambulation skills.

After stroke, individuals typically demonstrate reduced walking speed, decreased stride length and cadence, as well as temporal asymmetry. A systematic review[6] of ambulatory people after stroke reported mean walking speeds ranging from 0.4 to 0.8 m/s, compared with 1.0 to 1.2 m/s in healthy, older adults.[7] Previous studies[8,9] have also reported mean stride lengths ranging from 0.50 to 0.64 m in people after stroke, compared with 1.1 to 1.4 m in healthy, older adults, and mean cadence of 50 to 63 steps/minute, compared with 102 to 114 steps/minute in healthy, older adults.[7] Temporal symmetry of the affected leg to the non-affected leg is reported as ranging from 0.40 to 0.64, where 1.00 is symmetrical.[8,9] In summary, walking parameters in ambulatory people after stroke are approximately half of the values expected in older, able-bodied adults.

One approach that has the potential to improve multiple parameters of walking after stroke is cueing of cadence delivered via an external auditory cue during walking. Using a metronome or specifically prepared music tapes, the patient's steps are matched to the beat of the metronome or music in order to synchronise motor responses into stable time relationships.[8,9] The patient is asked to take steps according to the beat, so the rhythmic beat acts as a cue. If the beats are of a consistent frequency, this cueing will promote the temporal symmetry of walking. If the frequency of these consistent beats is increased, cadence and, therefore, speed will also increase. Whether stride length is also increased is an unanswered question. Therefore, cueing of cadence is an inexpensive adjunct to walking training, whether overground or on a treadmill, that has the potential to improve walking after stroke.

Three previous reviews have examined cueing of cadence but these have not used meta-analysis.[10–12] All three reviews included studies of all neurological conditions, but reported the studies relating to stroke separately. Thaut and Abiru[10] concluded that rhythmic auditory stimulation has a strong facilitating effect on

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walking, based on three trials.[8,9,13] Bradt et al[11] concluded that it may increase walking parameters such as step length, cadence and symmetry, based on two trials.[8,9] More recently, Wittner et al[12] concluded that there is moderate evidence that rhythmic auditory cueing improves walking speed and step length, but insufficient evidence of its effect on cadence and symmetry, based on three trials.[8,9,14] Two systematic reviews have examined the effect of exercise after stroke, which reported results on rhythmic auditory cueing separately. van Peppen et al[15] reported a standardised mean difference (SMD) of 0.91 (95% CI 0.40 to 1.42) on walking speed and 0.68 (95% CI 0.06 to 1.30) on step length, based on three trials,[8,13,16] whereas more recently, Veerbeek et al[17] reported a non-significant SMD of 0.6 (95% CI –1.8 to 3.0) on walking speed and 0.15 (95% CI –1.4 to 1.7) on stride length, based on two trials of early rehabilitation.[9,18] Given that different trials have been examined in different reviews, a meta-analysis of the current evidence for this promising intervention is warranted.

The aim of this systematic review was to examine the efficacy of the addition of cueing of cadence to walking training for improving walking after stroke. The specific research question was:

After stroke, is walking training with cueing of cadence superior to walking training alone in improving walking speed, stride length, cadence and symmetry?

In order to make recommendations based on a high level of evidence, this review included only randomised or controlled trials.

Method

Identification and selection of trials

Searches were conducted of Medline (1946 to August 2013), CINAHL (1986 to August 2013), EMBASE (1980 to August 2013) and PEDro (to August 2013) for relevant studies without date or language restrictions. The search strategy was registered at PubMed/Medline and the authors received notifications about potential papers related to this systematic review. Search terms included words related to *stroke*, words related to *randomised*, *quasi-randomised* or *controlled trials*, and words related to *cueing of cadence* (such as auditory cueing, rhythmic cueing, acoustic cueing and external cueing) (see Appendix 1 on the eAddenda for the full search strategy). In order to identify relevant studies, the titles and abstracts of the retrieved records were displayed and screened by two reviewers (LRN and CQO). Full paper copies of peer-reviewed relevant papers were retrieved and their reference lists were screened to identify further relevant studies. The method section of the retrieved papers was extracted and reviewed independently by two reviewers (LRN and CQO) using predetermined criteria (Box 1). Both reviewers were blinded to authors, journal and results. Disagreement or ambiguities were resolved by discussion with a third reviewer (LA).

Box 1. Inclusion criteria.

Design
- Randomised or controlled trials

Participants
- Adults (>18 years)
- Diagnosis of stroke
- Ambulatory (walking speed of at least 0.2 m/s at baseline or participants able to walk without help, with or without walking aids)

Intervention
- Experimental intervention is any method of walking training with cueing of cadence

Outcome measures
- Measures of walking (speed, stride length, cadence, symmetry)

Comparisons
- Walking training with cueing of cadence vs walking training alone

Assessment of characteristics of trials

Quality

The quality of included trials was assessed by extracting PEDro scores from the Physiotherapy Evidence Database (www.pedro.org.au). The PEDro scale is an 11-item scale designed for rating the methodological quality (internal validity and statistical information) of randomised trials. Each item, except for Item 1, contributes one point to the total score (range 0 to 10 points). Where a trial was not included on the database, it was scored by a reviewer who had completed the PEDro Scale training tutorial.

Participants

Ambulatory adults at any time following stroke were included. Ambulatory was defined as having a walking speed of at least 0.2 m/s at baseline or when the participants were able to walk without help, with or without walking aids. Studies were included when at least 80% of the sample comprised ambulatory participants. To assess the similarity of the studies, the number of participants and their age, time since stroke and baseline walking speed were recorded.

Intervention

The experimental intervention was any method of walking training accompanied by cueing of cadence delivered to individuals after stroke. The control intervention could be any walking training without cueing of cadence. To assess the similarity of the studies, the session duration, session frequency and program duration were recorded.

Measures

Four walking outcomes were of interest: speed, stride length, cadence and symmetry. To assess the appropriateness of combining studies in a meta-analysis, the timing of the measurements of outcomes and the procedure used to measure the different walking outcomes were recorded.

Data analysis

Information about the method (ie, design, participants, intervention and measures) and results (ie, number of participants and means (SD) of walking outcomes) were extracted by two reviewers and checked by a third reviewer. Where information was not available in the published trials, details were requested from the corresponding author.

The post-intervention scores were used to obtain the pooled estimate of the effect of intervention, using the fixed effects model. In the case of significant statistical heterogeneity ($I^2 > 50\%$), a random effects model was applied. Post-hoc sensitivity analysis was performed if the result of the random effects model was different from that of the fixed effect model. The analyses were performed using The MIX–Meta–Analysis Made Easy program Version 1.7.[19,20] Where insufficient data were available for a study result to be included in the pooled analysis, the between-group difference was reported. For all outcome measures, the critical value for statistical significance was set at a level of 0.05 (two-tailed). The pooled data for each outcome were reported as weighted mean differences (MD) with a 95% CI.

Results

Flow of trials through the review

The electronic search strategy identified 3830 papers, but 23 were duplicates. After screening titles, abstracts and reference lists, 32 potentially relevant full papers were retrieved. Twenty-five papers failed to meet the inclusion criteria (see Appendix 2 on

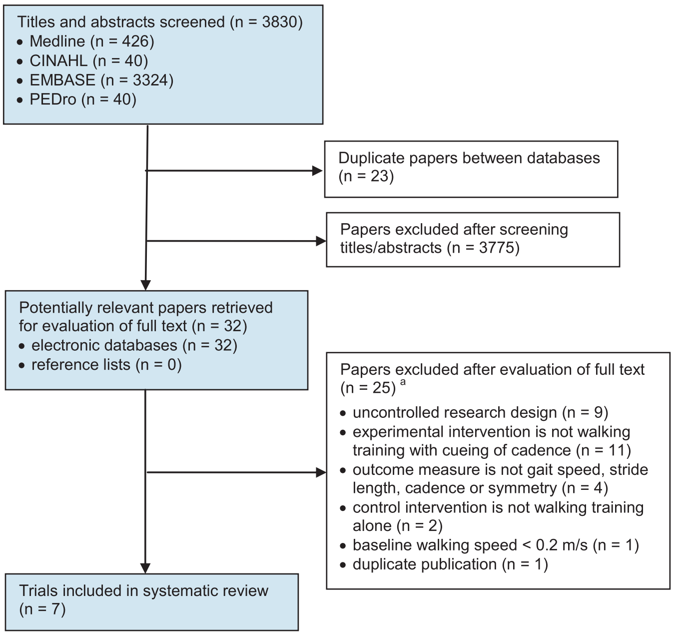

Figure 1. Flow of studies through the review.
[a]Trials may have been excluded for failing to meet more than one inclusion criterion.

the eAddenda for a summary of the excluded papers) and, therefore, seven papers were included in the review (Figure 1).

Characteristics of included trials

The seven trials involved 211 participants and investigated the efficacy of cueing of cadence for improving walking speed (n = 7), stride length (n = 7), cadence (n = 6) and symmetry (n = 5) after stroke (Table 1). All included trials compared walking training with and without cueing of cadence.

Quality

The mean PEDro score of the trials was 4.4 (range 3 to 7) (Table 2). All of the trials had similar groups at baseline and reported between-group differences. The majority of the trials (86%) randomly allocated participants and reported point estimate and variability. However, the majority of the trials did not: report concealed allocation (86%), carry out an intention-to-treat analysis (86%), have blinded assessors (86%), or have less than 15% dropout (70%). No trials blinded participants or therapists, which is difficult or impossible during complex interventions.

Participants

The mean age of participants ranged across the trials from 55 to 72 years. The mean time after stroke ranged across the trials from 2 weeks to 15 months. The majority of trials (71%) comprised

Table 1
Characteristics of included papers (n = 7).

Study	Design	Participants	Intervention	Progression	Outcome measures
Argstatter[18]	RCT	n = 40 Age (*yr*) = 55 to 80 Time since stroke (*mth*) = < 1 WS (*m/s*) = 0.23 (0.13)	Exp = CoC delivered via music (beats related to cadence) during walking training 10 min x 5/wk x 4 wk Con = Walking training without CoC 10 min x 5/wk x 4 wk	CoC increased by 5–10% of the initial walking speed	• speed • stride length • cadence • symmetry Timing: 0, 4 wk
Hayden[23]	CT	n = 10 Age (*yr*) = 55 to 80 Time since stroke (*mth*) = < 1 WS (*m/s*) = 0.49 (0.32)	Exp = CoC delivered via music (beats related to cadence) during walking training 10 min x 5/wk x 4wk Con = Walking training without CoC 10 min x 5/wk x 4 wk	CoC increased to match or slightly exceed patient's cadence by 1-3 beats/min	• speed • stride length • cadence Timing: 0, 4 wk
Kim[21]	RCT	n = 20 Age (*yr*) = 55 (13) Time since stroke (*mth*) = 5 (2) WS (*m/s*) = 0.54 (0.22)	Exp = CoC delivered via metronome during walking training 30 min x 3/wk x 5 wk Con = Walking exercises without CoC 30 min x 3/wk x 5 wk Both = usual therapy	CoC increased by 5% of comfortable speed and by lowering volume of the metronome.	• speed • stride length • cadence • symmetry Timing: 0, 5 wk
Kim[22]	RCT	n = 20 Age (*yr*) = 65 (7) Time since stroke (*mth*) = 15 (3) WS (*m/s*) = 0.63 (0.13)	Exp = CoC delivered via metronome during walking training 10 min x 3/wk x 6 wk Con = Walking training without CoC 10 min x 3/wk x 6 wk	CoC increased by 20 beats/min every 2 min	• speed • stride length • symmetry Timing: 0, 6 wk
Park[14]	RCT	n = 25 Age (*yr*) = 56 (12) Time since stroke (*mth*) = 15 (7) WS (*m/s*) = 0.37 (0.14)	Exp = CoC delivered via music (beats related to cadence) during walking training 2 x 30 min x 5/wk x 2 wk Con = Walking training without CoC 2 x 30 min x 5/wk x 2 wk	Not stated	• speed • stride length • cadence Timing: 0, 2 wk
Thaut[8]	RCT	n = 20 Age (*yr*) = 72 (7) Time since stroke (*mth*) = 0.5 (0.1) WS (*m/s*) = 0.31 (0.20)	Exp = CoC delivered via musical feedback enhanced by metronome beats during walking training 2 x 30 min x 5/wk x 6 wk Con = Walking training without CoC 2 x 30 min x 5/wk x 6 wk Both = pre- gait exercises if indicated	Cadence measured at the beginning of each session and CoC increased from 5–10% at the second and third quarter	• speed • stride length • cadence • symmetry Timing: 0, 6 wk
Thaut[9]	RCT	n = 78 Age (*yr*) = 69 (11) Time since stroke (*mth*) = 0.7 (0.4) WS (*m/s*) = 0.23 (0.11)	Exp = CoC delivered via musical feedback enhanced by metronome beats during walking training 30 min x 5/wk x 3 wk Con = Walking training without CoC 30 min x 5/wk x 3 wk Both = pre- gait exercises if indicated	Cadence measured at the beginning of each session and CoC increased 5% during the second quarter	• speed • stride length • cadence • symmetry Timing: 0, 3 wk

Groups and outcome measures listed are those that were analysed in this systematic review; there may have been other groups or measures in the paper. Numerical data under participant characteristics are mean (SD), or range.
CoC = cueing of cadence, Con = control group, CT = controlled trial, Exp = experimental group, RCT = randomised clinical trial, WS = walking speed.

Table 2
PEDro criteria and scores for included papers (n = 7).

Study	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	< 15% dropouts	Intention-to-treat analysis	Between-group difference reported	Point estimate and variability reported	Total (0 to 10)
Argstatter[18]	Y	N	Y	N	N	N	N	N	Y	Y	4
Hayden[23]	N	N	Y	N	N	N	N	N	Y	Y	3
Kim[21]	Y	N	Y	N	N	N	Y	N	Y	Y	5
Kim[22]	Y	N	Y	N	N	N	N	N	Y	Y	4
Park[14]	Y	N	Y	N	N	N	Y	N	Y	Y	5
Thaut[8]	Y	N	Y	N	N	N	N	N	Y	N	3
Thaut[9]	Y	Y	Y	N	N	Y	N	Y	Y	Y	7

Y = yes; N = no.

participants in the acute/sub-acute phases of stroke on admission to the trial.

Intervention

In all trials, the experimental intervention was overground walking training with cueing of cadence. Cueing of cadence was delivered via metronome beats in two trials,[21,22] via music beats in three trials,[14,18,23] and via music enhanced by metronome beats in two trials.[8,9] Participants undertook training for 10 to 30 minutes, once or twice a day, three to five times per week, for 3 to 6 weeks. The control group received overground walking training without cueing of cadence in all trials.

Outcome measures

Three trials[8,9,18] used foot sensors during a timed walk test to obtain the walking parameters, two trials[21,22] used computerised platforms, and two trials[14,23] used a timed walk measure.

Only two trials[9,18] reported walking symmetry as a ratio of a temporal aspect of the affected leg to the non-affected leg. Walking symmetry for another three trials[8,21,22] was calculated from available data and reported as a ratio of a temporal aspect of the affected leg and the non-affected leg. Cycle time values were used for calculations in one trial,[21] support time was used in one trial,[22] and swing time was used in one trial.[8] Two trials[14,23] did not provide data related to walking symmetry.

Walking speed was converted to m/s, stride length to m, cadence to steps/minute, and symmetry to a ratio where 1.0 is symmetrical.

Effect of cueing of cadence

Walking speed

The effect of cueing of cadence during walking training on speed was examined by pooling post-intervention data from seven trials involving 211 participants. There was substantial statistical heterogeneity (I^2 = 75%), indicating that the variation between the results of the trials is above the variation expected by chance. When a random effects model was applied, the mean effect was different and a sensitivity analysis was therefore performed. The sensitivity analysis revealed that the heterogeneity was not explained by the quality of the trials, assessor blinding, numbers of participants or initial walking speed, but was explained by one trial that was so different from the other trials that the lower limit of the confidence interval of the meta-analysis did not cross that trial's mean effect; therefore, the meta-analyses were conducted both with this outlying trial[18] included and excluded. The data from the remaining six trials involving 171 participants indicated that walking training with cueing of cadence improved walking speed by 0.23 m/s (95% CI 0.18 to 0.27, I^2 = 0) more than walking training alone (Figure 2, see Figure 3 on the eAddenda for the detailed forest plot and the meta-analysis with the outlying trial included).

Walking stride length

The effect of cueing of cadence during walking training on stride length was examined by pooling post-intervention data from six trials involving 171 participants. Walking training with cueing of cadence improved walking stride length by 0.21 m (95% CI 0.14 to 0.28, I^2 = 18%) more than walking training alone (Figure 4, see Figure 5 on the eAddenda for the detailed forest plot and the meta-analysis with the outlying trial included).

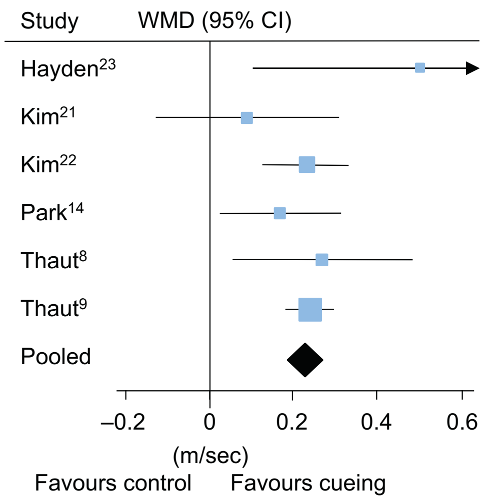

Figure 2. Mean difference (95% CI) of walking training with cueing of cadence versus walking training alone for walking speed (n = 171).

Walking cadence

The effect of cueing of cadence during walking training on cadence was examined by pooling post-intervention data from five trials involving 151 participants. Walking training with cueing of cadence improved walking cadence by 19 steps/minute (95% CI 14 to 23, I^2 = 40%) more than walking training alone (Figure 6, see Figure 7 on the eAddenda for the detailed forest plot and the meta-analysis with the outlying trial included).

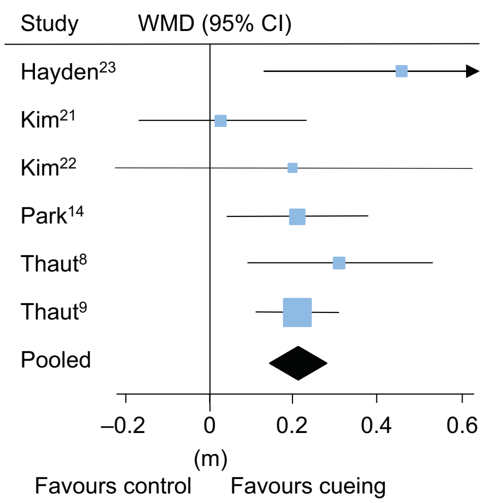

Figure 4. Mean difference (95% CI) of walking training with cueing of cadence versus walking training alone for stride length. (n = 171).

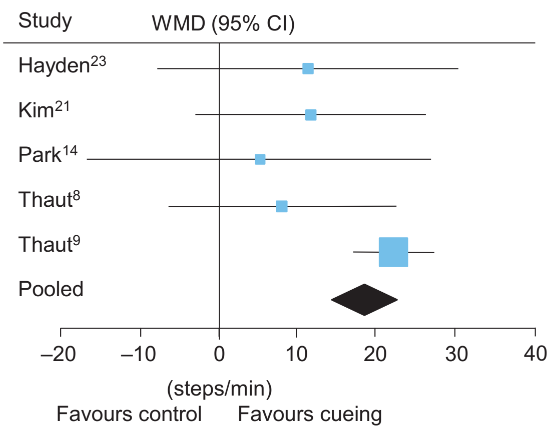

Figure 6. Mean difference (95% CI) of walking training with cueing of cadence versus walking training alone for cadence (n = 151).

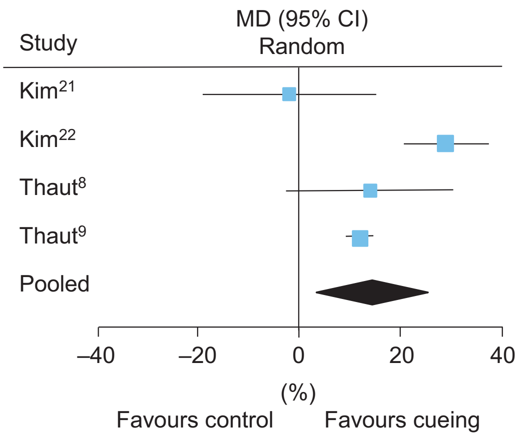

Figure 8. Mean difference (95% CI) of walking training with cueing of cadence versus walking training alone for symmetry (n = 136).

Walking symmetry

The effect of cueing of cadence during walking training on symmetry was examined by pooling post-intervention data from four trials involving 136 participants. Walking training with cueing of cadence improved walking symmetry by 13% (95% CI 11 to 16). There was, however, substantial statistical heterogeneity (I^2 = 80%), indicating that the variation between the results of the trials was above the variation expected by chance. A random effects model was applied and the results indicated that walking training with cueing of cadence improved walking symmetry by 15% (95% CI 3 to 26) more than walking training alone (Figure 8, see Figure 9 on the eAddenda for the detailed forest plot and the meta-analysis with the outlying trial included).

Discussion

This systematic review provides evidence that walking training with cueing of cadence can improve walking parameters after stroke more than walking training alone. Meta-analysis with low statistical heterogeneity indicated that the addition of cueing of cadence produced more benefit in terms of walking speed and stride length than walking training alone. Meta-analysis with higher heterogeneity also suggested that the addition of cueing of cadence produced more benefit in terms of cadence and symmetry than walking training alone.

The pooled effect from the meta-analysis indicated that walking training with cueing of cadence resulted in 0.23 m/s faster walking and 0.21 m longer stride length than walking training alone. A recent meta-analysis[17] of rhythmic gait cueing produced non-significant results for walking speed and stride length, based on two trials with 97% statistical heterogeneity. A previous meta-analysis[15] of external auditory rhythms produced significant results for walking speed (MD 0.22 m/s) and stride length (MD 0.18 m), based on three trials. Although effect sizes from the earlier review[15] are similar to those found in our review, only one of the included trials is common to both reviews. Our review strengthens the evidence about the efficacy of the addition of cueing of cadence to walking training for increasing walking speed and stride length after stroke; this is because the conclusions are based on a meta-analysis of six trials that provided a specific intervention (ie, beats from metronome or beats from music delivered during walking).

These results have important clinical implications. The improvement of 0.23 m/s on walking speed appears to be clinically meaningful. According to Tilson et al,[24] people with sub-acute stroke, whose gait speed increases by at least 0.16 m/s, are more likely to experience a meaningful reduction in disability. A second study has also indicated that an improvement in gait speed of 0.13 m/s or more, over the course of rehabilitation, is clinically important in people with stroke.[25] In addition, the improvement in walking speed was accompanied by an improvement in stride length, which suggests that the addition of cueing of cadence to walking training is not detrimental to the quality of movement. This is an important finding because clinicians have been cautious about increasing the tempo of beats during walking training in case any increases in cadence and speed occur at the expense of stride length, which would be undesirable. Moreover, the addition of cueing of cadence to walking training has larger effects than other interventions, such as treadmill training (MD 0.05 m/s, 95% CI –0.12 to 0.21, meta-analysis of three trials)[6] and virtual-reality training (MD 0.15 m/s, 95% CI 0.05 to 0.24, meta-analysis of five trials),[26] compared with walking training alone. Clinically, cueing of cadence is an easy intervention to implement, not only because it is inexpensive, but also because it can be applied in community settings and does not require close professional supervision for safety. Cueing of cadence can also be added to different walking interventions (eg, treadmill training) and may thereby increase the effect of the intervention.

This review has both limitations and strengths. The mean PEDro score of 4.4 for the included trials represents moderate quality. A source of bias in the included trials was lack of blinding of therapists and participants, since it is very difficult to blind either during the delivery of complex interventions. Other sources of bias were non-blinding of assessors, not reporting concealed allocation, or not reporting that an intention-to-treat analysis was undertaken. The number of participants per group (mean 15, range 5 to 39) was quite low, opening the results to small trial bias. In addition, maintenance of benefits beyond the intervention period was not examined. On the other hand, after removal of one trial,[18] statistical heterogeneity of the trials pooled in the meta-analysis was low for walking speed and stride length, leading to robust findings about the effect of cueing of cadence. Overall, the included trials were similar regarding their clinical characteristics. Most of trials included participants in the sub-acute phase of rehabilitation (five out of seven trials) and initial walking speed ranging between 0.23 and 0.63 m/s across trials, indicating that most of the participants could be classified as moderately disabled.[27] A major strength of this review is that only trials whose intervention was cueing of cadence via beats from a metronome or beats from music during walking training were included; this constrains the results to a specific intervention. Although the session duration between trials included in the meta-analysis varied (mean 33 minutes, SD 22), the trials had similar session frequencies (mean 4.3 per week, SD 1.0), and program durations (mean 4.3 per week, SD 1.6). Publication bias inherent to systematic reviews was avoided by including studies published in languages other than English.[18] The evidence, therefore, appears strong enough to recommend the addition of cueing of cadence to daily walking training in order to increase walking speed and stride length after stroke. In addition, walking training with cueing of cadence may have positive effects on cadence and symmetry; however, additional randomised clinical trials are warranted in order to reduce the level of uncertainty related to the wide confidence intervals regarding the difference between groups for those outcomes.

In conclusion, this systematic review provides evidence that an inexpensive and easy-to-implement intervention – walking training with cueing of cadence – is more effective than walking training alone in improving walking after stroke. Walking training with cueing of cadence produced faster walking and longer stride length, and may have positive effects on cadence and symmetry. The results of a meta-analysis based on six trials indicate that the addition of 30 minutes of cueing of cadence to walking training four times a week for 4 weeks can be expected to improve walking in moderately disabled individuals with stroke. Future studies are recommended to verify if the benefits of cueing of cadence to walking training are maintained beyond the intervention period.

What is already known on this topic: Stroke can cause reduced walking speed, decreased stride length, slower cadence and temporal asymmetry of gait. Rhythmic auditory beats can be used to cue cadence, to guide speed and to promote symmetry.
What this study adds: After stroke, walking training with cueing of cadence is more effective than walking training alone in improving walking. Walking speed and stride length clearly improve, and cadence and symmetry may also improve.

eAddenda: Figures 3, 5, 7 and 9, and Appendices 1 and 2 can be found online at doi:10.1016/j.jphys.2014.11.015.

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Competing interests: None declared.

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