Physiotherapy and Health Activity
www.ptha.eu pha@awf.katowice.pl
2020; 28:83-93 ISSN: 2392-2664

DOI: 10.32087/pha-2020-0010

The use of Nordic walking and rhythmic auditory stimulation in neuromotor rehabilitation: a literature review

Received: 01-07-2020

Accepted: 03-09-2020

Published: 20-10-2020

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Abstract:

The nervous system is responsible for balance and locomotion, while its capacity determines walking as a complex motor activity. However, recovery of locomotion function is a long-term process. Neuromotor rehabilitation methods combining conventional rehabilitation with sensorimotor stimulation based on the use of auditory stimuli or coordination integration should be further developed while new relationships between the stimuli used and the effects obtained should be examined. One of the interesting proposals to combine these two aspects is the use of gait rehabilitation in combination with rhythmic auditory stimulation (RAS). All literature reports published to date have supported the thesis of the beneficial effects of RAS on the results obtained in patients with gait disturbances. Another example of using popular forms of physical activity in rehabilitation programs is walking with poles, known as Nordic walking (NW). Despite its short history, the sport has gained much popularity among the forms of physical activity used not only for recreational purposes but also for improving health. This study attempts to present the current state of knowledge on the benefits of Nordic walking and the effect of the use of metrorhythmic stimulation on the outcomes of neuromotor rehabilitation. For this purpose, the databases of the libraries in two universities in Poland (the Jerzy Kukuczka Academy of Physical Education in Katowice and the Silesian University of Technology in Gliwice) were searched. Furthermore, available online public databases (PubMed and Google Scholar) were also used. More than 500 papers were found. However, based on the inclusion criteria used, only 28 literature items were selected for further analysis. In conclusion, based on the knowledge gained, both the forms of physical activity that use RAS and those based on Nordic walking can have a positive effect on locomotor function in patients.

Keywords:

rhythmic auditory stimulation, neuromotor control, neurorehabilitation, Nordic walking

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How to cite the paper:

Kania D, Romaniszyn –Kania P, Mańka A, Myśliwiec A, Mitas AW. The use of Nordic walking and rhythmic auditory stimulation in neuromotor rehabilitation: a literature review. Physiother Health Act 2020; 28:83-93. DOI: 10.32087/pha-2020-0010

Introduction

The nervous system is responsible for balance and locomotion, while its capacity allows for performing such complex motor activities as walking [1]. According to the International Classification of Diseases ICD-10, mobility disorders are numbered among the symptoms and characteristics of diseases affecting not only the nervous system but also the musculoskeletal system [2]. Statistical data show that as much as 10% of the population at the age from 60 to 69 years and over 60% of people aged over 80 suffer from gait disorders [3]. However, motor function impairment can occur in anyone, regardless of age, and there are many potential causes. The most frequent walking disorders are consequences of such diseases as Parkinson's disease, Alzheimer's disease, multiple sclerosis, muscular dystrophy, and stroke [4]. Unfortunately, in most cases, these symptoms cannot be completely cured, and therefore the focus should be on using existing and searching for new methods to restore the patient's motor abilities at the highest possible level.

Restoring locomotor functions is a long -term process. The precondition is the patient's ability to maintain balance in the standing position. Popular methods of restoring balance are e.g. proprioceptive neuromuscular facilitation (PNF) [5-9] or the use of specialized equipment (e.g. Lokomat devices) to improve patients' function [10-13].

With the development of technology, which is becoming more and more common in the everyday life of every person, it is necessary to look for solutions that combine conventional gait reeducation with modern methodologies. One of the interesting proposals to combine these two aspects is the use of gait rehabilitation in combination with rhythmic auditory stimulation (RAS). This method was first proposed by M. Thaut in 1996 to be used in the training of patients with Parkinson's disease [15]. Much research has been done to date on the effectiveness of using RAS in therapy and the results of this combination. According to the author's knowledge, previous reports have supported the thesis of the beneficial effect of RAS on the results obtained in patients with gait disturbances, not only in Parkinson's disease but also after a stroke or other neurological diseases [15-25].

However, in addition to the methods broadly described in the literature, there are other forms of rehabilitation which, from the patient's perspective, are not identical to the typical therapy in a physiotherapy room. One example of using popular forms of physical activity in rehabilitation programs is Nordic walking (NW). Despite its short history, the sport has gained much popularity among the forms of physical activity used not only for recreational purposes but also for improving health. In addition to the improved locomotion, this type of walking can be used by people of all ages to develop endurance, strength, coordination, and the ability to maintain balance [27-41].

Neuromotor rehabilitation methods combining conventional rehabilitation with sensorimotor stimulation based on the use of auditory stimuli or coordination integration should be further developed while new relationships between the stimuli used and the effects obtained should be examined. Therefore, this study attempts to present the current state of knowledge on the benefits of Nordic walking and the effect of the use of metrorhythmic stimulation on the outcomes of neuromotor rehabilitation.

Material and Methods

Knowledge sources and search strategy

The review of the literature reports focused on the problems related to the benefits of using Nordic walking in gait rehabilitation and the effect of

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metrorhythmic stimulation on the outcomes of neurorehabilitation. The search was conducted by the research team in the period from January to April 2020. For this purpose, the databases of the libraries in universities in Poland, including the Jerzy Kukuczka Academy of Physical Education in Katowice and the Silesian University of Technology in Gliwice, were searched. Furthermore, available online public databases (PubMed and Google Scholar) were also used.
More than 500 articles were found based on the search, but many of them failed to meet the criteria presented in the next chapter.

Selection criteria

In the presented literature review, the stages of the search were divided into two categories. The first category concerned the outcomes of neuromotor rehabilitation with the use of Nordic walking, with the papers searched using the following keywords: *gait parameters nordic walking, locomotor system nordic walking, effects of nordic walking, physical functions nordic walking, nordic walking mechanical and physiological effects, pelvic rotation nordic walking, faulty postures nordic walking, scoliosis nordic walking, postures nordic walking, strengthening muscles nordic walking*. For the second category of the search concerning the outcomes of metrorhythmic stimulation on the outcomes of rehabilitation, the keywords were *music during nordic walking, acoustic feedback, music stimulation during walking, nordic walking rhythmic auditorory stimulation, rhytmic auditorory stimulation during gait*. Based on the experience of the research team, the following inclusion criteria were proposed:

a) the subject matter of the research concerned the categories listed above,
b) the paper was a research study rather than a literature review,
c) the type of paper was important: only clinical research, preliminary research, individual case studies, and the latest reports on the problem discussed were taken into account,
d) papers were written in English,
e) the papers should have been published within 5 years before 1 January 2015, except for those on established rehabilitation techniques and major reports in the field.

Data extraction

More than 500 articles were found based on the keywords presented above. However, only 28 of them met the inclusion criteria and were taken into account in further literature analysis.

Results

Metrorhythmic stimulation in neuromotor rehabilitation

The variety of aspects that should be assessed during the analysis of the parameters that reflect the effects of therapy is wide. In the presented literature, the following gait indices were mostly analysed: speed, cadence, and stride length. The results of functional tests to which the patients were subjected (e.g. the Berg Balance Scale) were also taken into account. The table below (Tab. 1) enumerates papers on the benefits of metrorhythmic stimulation in neurological rehabilitation.

Neuromotor rehabilitation using Nordic walking

People have used rehabilitation since the dawn of time. Already in ancient Egypt, one of the basic forms of therapy for the sick were games and playing, with their main objective being to activate patients by performing specific activities that improve both the mental and physical

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Table 1. List of papers on the use of RAS in neurorehabilitation

Year	Authors	Aim of the study	Parameters analysed	Material	Conclusion
1996	Mainka S., Wissel J., Völler H., Evers S.	Evaluation of the effectiveness of metrorhythmic stimulation (RAS) and treadmill training (TT) on functional gait in stroke patients.	Results of fast gait test (FGS), gait analysis with locometre (LOC), 3-min walking test (3MWT), and instrumental evaluation of balance (IEB).	45 stroke patients with hemiparesis of the lower limb and asymmetrical walking pattern treated for 4 weeks (RAS+TTT/ Bobath+TT)	Higher effectiveness of RAS+TT compared to Bobath+TT during restoring functional gait after a stroke.
2019	Elsner B, Schöler , Kon T., Mehrholz J.	Evaluation of the effect of two different programs of rehabilitation on treadmill for chronic stroke patients.	Gait speed, stride length, balance evaluation according to the Berg Balance Scale.	12 patients divided into two groups: gait training with and without RAS, 30 minutes, three times a week for 4 weeks.	Neurorehabilitation with the use of RAS does not provide a beneficial effect on patients' gait after a stroke.
2019	Calabrò R.S., Naro A., Filoni S et. al.	To determine which mechanisms allow for improved gait in patients with Parkinson's disease.	Functional gait indices: stride length, gait speed, UPDRS, Tinetti Falls Efficacy Scale.	50 PD patients for 8 weeks undergoing treadmill rehabilitation with and without RAS.	Adequate identification of mechanisms is critical to create patient-tailored RAS-based rehabilitation approaches to treat PD patients.
2016	Ko B.W., Lee H.Y., Song W.K.	Effect of different tempos of rhythmic auditory stimulation (RAS) on changes in gait pattern in stroke patients.	Stride length, gait speed and cadence, gait cycle duration, step length for the affected and unaffected foot, symmetry coefficient.	15 stroke patients undergoing treadmill rehabilitation with and without RAS (different music tempos).	Significant changes in motor activity in stroke patients treated with RAS compared to the control group.
2014	Benoit C.E., Dalla Bella S., Farrugia N., Obrig H., Mainka S., Kotz S.A.	Evaluation of the effectiveness of the use of music in the training of motor control and perception in Parkinson's disease.	Evaluation of the perception of pulse, UPDRS, Token test.	15 PD patients 49 to 80 years old, undergoing 4-week rhythmic training; 15-minute sessions 3 times a week for a month.	Improved patient performance in tasks requiring synchronization with isochronous sequences and enhanced ability to adapt to durational changes.
2008	Arias P., Cudeiro J.	Evaluation of the effect of RAS on PD patients with freezing of gait (FoG)	UPDRS, gait speed and cadence, step length, rotation time.	20 FoG-PD patients were divided into two groups: therapy with and without RAS.	The use of RAS therapy contributed to a significant reduction in FoG, and increased gait speed and cadence.
2008	Kobinata N., Ueno M., Imanishi Y., Yoshikawa H.	Analysis of the effect of RAS on gait in stroke patients in different lesion sites.	Gait speed and cadence, stride length.	105 stroke patients (5 groups depending on the lesion site) performed a 10-meter walk without and with RAS.	A significant increase in gait speed and stride length in the RAS test.
2016	Schreiber C., Remacle A., Chantraine F., Kolanowski E., Moissenet F.	Comparison of gait characteristics in patients with gait dysfunction at preferred and reduced walking speeds with and without RAS stimulation.	Gait cadence and speed, double-support time, symmetry, stride length, path length, step width.	17 patients, a gait test was performed for 10 meters in 4 cycles: preferred speed without RAS, preferred speed with RAS, reduced speed without RAS, reduced speed with RAS.	Statistically significant differences between groups with and without RAS were found for stride length and step width, path length, and gait speed.

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Table 1. Cont.

Year	Authors	Aim of the study	Parameters analysed	Material	Conclusion
2016	Song G. B., Ryu H. J.	Comparison of motor abilities in stroke patients after rehabilitation with and without RAS.	Gait cadence, stride length, dynamic gait indicator.	Two gait training groups (20+20), with and without RAS, for 30 minutes, five times a week for one month.	Better results were obtained in the training group with RAS: a greater increase in gait cadence, a longer stride and an increase in the dynamic gait index.
2016	Pau M., Corona F, Pili R. et. al.	Evaluation of walking kinematics in PD patients after training with and without RAS.	Gait Profile Score (GPS), Gait Variable Score (GVS), gait speed, stride length.	Two groups (13+13) undergoing gait rehabilitation (with and without RAS) for 5 weeks, three-dimensional gait analysis based on optoelectronic stereophotogrammetry.	Gait training using RAS was shown to be more effective due to the increased gait speed and stride length, general improvement in walking quality, decreased GPS, and GVS.
2017	Shahraki M., Sohrabi M., Torbati H. T., Nikkhah K., Naeimi Kia M.	Evaluation of the effect of the use of RAS in the rehabilitation on gait kinematic parameters in patients with multiple sclerosis (MS).	Stride length, stride time, double support time, cadence, and gait speed.	18 patients with MS divided into two groups: gait training with and without RAS, 30 minutes, three times a week for 3 weeks.	Rehabilitation with RAS is an effective method to improve gait kinematic parameters in patients with MS. Statistically significant differences in stride length, stride duration, double support time, gait cadence between groups with and without RAS.
2019	Romaniszyn P., Kania D., Nowakowska K., et. al.	Evaluation of the effect of therapies with and without RAS in stroke patients.	Symmetry of lower limb loads, path length, CoP.	4 people (3 stroke patients, 1 healthy person), 4 exercises in two series.	It is impossible to indicate a clear effect of RAS on the symmetry of lower limb loads during physiotherapy exercises in stroke patients.

spheres. In the 1920s, a new form of recreation was invented in Finland, consisting in walking with special poles, called Nordic walking. This walking technique has become very popular because of its wide range of applications: in addition to recreation, it contributes to the improvement of general health and motor control indices. Studies on the use of Nordic walking in neuromotor rehabilitation are enumerated in the table below (Table 2).

Discussion

The increasing number of people in the world who need rehabilitation and the constant development of technology will contribute to a greater extent. Gait pathologies are a particularly important type of disorders that affect an increasing percentage of the population. They result from the nervous system dysfunctions caused by various diseases such as Parkinson's disease or stroke.

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Table 2. List of papers on the use of Nordic walking in gait rehabilitation

Year	Authors	Aim of the study	Parameters analysed	Material	Conclusion
2015	Warlop T., Detrembleur C., Lopez et. al.	Study of the effect of Nordic walking on the dynamic stability of human gait in Parkinson's disease.	Spatiotemporal parameters of gait: stride length, gait variability.	2 training sessions (14 PD patients): walking sessions (with and without pole) in random order.	Gait speed remained constant, gait cadence decreased, and stride length increased significantly when using NW therapy.
2017	Monteiro E. P., Franzoni L. T., et. al.	Comparison of the effect of NW and free walking (FW) training program on functional parameters, self-selected walking speed (SSW), and locomotor rehabilitation index in PD patients.	Comparative results of tests such as UPDRS III, Up&Go, the Berg Balance Scale, and locomotor rehabilitation index LRI.	33 patients with PD, divided into rehabilitation groups using NW, FW, and a control group.	Rehabilitation using NW gives measurable benefits as it improves the functional parameters of gait.
2011	Reuter I., Mehnert S., Leone P., Kaps M., Oechsner M., Engelhardt M.	Study of the effects of flexibility and relaxation programme, walking, and Nordic walking on gait parameters and quality of life in PD patients.	Walking speed, stride length, stride length variability.	90 patients with PD Six-month training plan, three times a week, 70 minutes per session.	Rehabilitation using Nordic walking improves the quality of life and reduces pain in PD patients. It also helps extend stride, improve maximum speed, gait pattern, gait variability, and postural stability.
2013	Figueiredo S., Finch L., Mai J., Ahmed S., Huang A., Mayo N. E.	The improvement of walking ability through training with the use of Nordic walking compared to usual overground walking.	The distance covered during the 6-minute walk test (6MWT) and the gait speed.	30 patients aged 65 to 92 years.	NW causes a significant increase in endurance and gait speed (by 106%).
2015	Park S. K., Yang D. J., Kang Y. H., Kim J. H., Uhm Y. H., Lee Y. S.	Study of the effect of Nordic walking and walking on spatiotemporal walking parameters and the ground reaction force.	Gait cadence, stride length, stride time, vertical ground reaction force.	30 people were examined, their walk with and without NW was analysed using the Vicon MX motion analysis system During the examination, they had to walk 12 meters with and without NW.	NW led to a significant increase in the parameters of gait cadence, an increase in length, and a decrease in the stride time.
2015	Kocur P., Wiernicka M., Wilski M., et. al.	Evaluation of the effect of 12-week Nordic walking training on gait parameters and postural control.	Forward Reach Test (FRT) and Upward Reach Test (URT) scores, gait cycle length, gait cycle frequency.	67 people, 12 weeks of NW training, 3 times a week for 75 minutes	Training with the use of NW contributed to the improvement in the FRT and URT test results, extended the stride, increased gait cycle frequency, and improved postural control.
2016	Homma D., Jigami H., Sato N.	Evaluation of the effect of Nordic walking training on pelvis motion and muscle activity around the hip joints in adults with hip osteoarthritis.	Pelvic rotation angle and muscle activity with accelerometers and EMG.	10 patients undergoing training using Japanese-style NW and European-style NW and ordinary walking.	NW causes a larger pelvic rotation angle compared to OW, it also contributes to increased activity of the rectus abdominis muscle and lower activity of the lumbar muscles, and it reduces the compensatory pelvic rotation.

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Table 2. Cont.

Year	Authors	Aim of the study	Parameters analysed	Material	Conclusion
2017	Pšurný M., Janura M., Svoboda Z., Kopynová A.	Comparison of the range of motion of the trunk and upper limbs during NW with conventional walking (W) at different walking speeds and ground slopes.	The range of motion of the pelvis in the sagittal plane, analysis of gait kinematics using Vicon MX system.	16 patients walking on a treadmill with and without NW poles	For the walk with NW poles, the range of pelvis and elbow mobility increased significantly. Higher gait speed in NW group was also observed compared to conventional walking.
2018	Pellegrini B., Boccia G., Zoppirolli C., et. al.	Evaluation of differences in muscle activation during Nordic walking (NW) and walking (W).	The level of muscle activation assessed using EMG.	Ten volunteers trained on a treadmill consecutively with (NW) and without (W) the use of Nordic walking poles.	Increased activation of shoulder extensor muscles in Nordic walking NW compared to conventional walking. The correct NW technique is critical in rehabilitation because improper and incompetent walking with poles can cause deterioration of health or lead to injuries.
2015	Pellegrini B., Peyré-Tartaruga L. A., Zoppirolli et. al.	Evaluation of differences in muscle activation and physiological reactions between NW and W.	Level of muscle activation with EMG (7 upper and 5 lower body muscles).	9 women (NW instructors) performed 5-minute tests on a treadmill with and without NW at 4 km/h and inclines of 0% and 15%.	Muscle activity during NW increased significantly compared to W. NW reduces the contraction of the muscles of the lumbar back.
2015	Hanuszkiewicz J., Malicka I., Barczyk-Pawelec K., Woźniewski M.	Evaluation of the effect of various forms of physical activity, including NW, on the sagittal posture in women after breast cancer treatment.	Angles to assess the quality of body posture.	Photogrammetric examination was performed in 60 women who had received breast cancer treatment to assess their posture before and after 8 weeks of NW training.	NW helped reduce the angle of thoracic kyphosis and lumbar lordosis after NW training compared to the general fitness exercise.
2013	Song M. S., Yoo Y. K., Choi C. H., Kim N. C.	Study of the effect of NW training on body composition, muscle strength, and lipid profile in elderly women.	Body weight, body mass indices, total body water, muscle mass, skeletal mass, percent body fat, grip strength, LDL, HDL, body position, arm curl.	67 women aged 65 or older trained 3 times a week for 4 months.	NW led to an increased range of arm curl, grip strength and it was observed that NW is more effective in improving upper limb strength compared to normal walking.
2015	Virág A., Karóczi C. K., Jakab A., Vass Z., Kovacs E., Gondos T.	Long-term assessment of the effects of the use of NW in older people.	Body balance, functional mobility, strength of lower and upper limbs.	41 people aged over 60 years performed NW training with supervision for 10 weeks and without supervision for 25 weeks.	No significant differences in muscle strength were found between supervised and unsupervised training. NW can play a key role in geriatric physiotherapy as it helps improve and maintain functional abilities.

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Table 2. Cont.

Year	Authors	Aim of the study	Parameters analysed	Material	Conclusion
2006	Kleindienst F. I., Michel K. J., Schwarz J., Krabbe B.	Study of differences between the NW and walking locomotion patterns.	Lower limb load	11 people	In NW, the load is lower than in conventional walking, however, there are no physiological benefits from the parameters.
2016	Dalton C., Nantel J.	Examination of gait patterns and their improvement after NW training compared to normal walking.	Step length, stride length, cadence, double support, single support, gait speed, energy absorption in joints.	20 people aged 60 to 80 years were evaluated using accelerometers, gyroscopes, and a force platform.	An overall improvement in the patient's health status was observed after NW training. The step and stride were extended, the patients walked faster, and increased power generation at the hip and knee and a significant improvement in balance were observed.

Unfortunately, in most cases, patients cannot regain their full locomotor abilities, which is why the right choice of therapy is so critical. One of the innovative methods that help improve motor function is to combine of conventional rehabilitation and rhythmic auditory stimulation. Many studies in the literature have focused on the assessment of the effectiveness of the use of RAS in gait training in patients with various dysfunctions. In these studies, the values concerning gait kinematics were analysed, including gait speed and cadence, stride length, and the position of the centre of gravity [17-19,21-27]. Furthermore, patients are examined by means of functional tests reflecting the ability to maintain balance and general motor abilities [15-18,20,21]. All the above-mentioned studies demonstrated significant changes in the motor activity of people with neurological diseases and substantial improvements in gait parameters (increased gait speed and cadence, stride length) during therapies based on the use of RAS.

Another technique that patients associate with a more recreational form of activity is neuromotor rehabilitation using Nordic walking. Perhaps this method seems trivial to many but looking at this aspect from the scientific point of view, a dynamic walking with poles contributes to the activation of many muscle groups and the general improvement of functional gait parameters, with numerous literature reports providing evidence [27-41].

During the therapy, parameters such as stride length, stride variability, gait speed, and gait cadence were analysed [27,29,31,41]. Similarly to therapies using RAS, patients performed functional tests such as Up&Go, Berg Balance Test, and the 6-minute walk test [28,30,32].

Furthermore, to thoroughly assess the level of activation of individual muscles, electromyography (EMG) was performed [33,35,36], and the range of pelvic mobility and angles used to evaluate the quality of body posture were measured [33,34,37,38]. All the above studies indicated that neuromotor rehabilitation using Nordic walking is more effective than that using conventional walking. A general improvement in both physical and mental health and reduced pain was found in NW patients.

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In conclusion, it should be emphasized that both the forms that use RAS and those based on Nordic walking can have a positive effect on locomotor function in patients. However, rhythmic auditory stimulation is still uncommon even though the first references to use it date back to 20 years ago. This may result from the fact that the mechanism of rhythmic auditory stimulation is not sufficiently well understood, which limits the effective use of this type of therapy.

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