Obstacle avoidance in persons with rheumatoid arthritis walking on a treadmill

E. Smulders[1,2], C. Schreven[1], W. van Lankveld[1,3], J. Duysens[1,2,4] , V. Weerdesteyn[1,2,5]

[1]Research, Development and Education, Sint Maartenskliniek, Nijmegen, The Netherlands; [2]Institute for Fundamental and Clinical Human Movement Sciences, Vrije Universiteit, Amsterdam, The Netherlands; [3]Department of Rheumatology, Sint Maartenskliniek, Nijmegen, The Netherlands; [4]Department of Biomedical Kinesiology (FaBeR), K.U. Leuven, Belgium; [5]Department of Rehabilitation, Radboud University, Nijmegen Medical Centre, Nijmegen, The Netherlands.

Abstract

Objective

Patients with rheumatoid arthritis (RA) are at increased risk of falling. In healthy elderly persons with a history of falling, a reduced ability to avoid obstacles while walking has been shown to relate to increased fall risk. The aim of this study was to determine whether this potential risk factor for falls would also be present in persons with RA.

Methods

Twelve RA patients and twelve controls performed an obstacle avoidance task on a treadmill. The obstacle was released during three different phases of the gait cycle (late stance, early swing and mid swing) to create increasing difficulty levels. The primary outcome measure was failure rate.

Results

Overall, the RA patients had significantly higher obstacle avoidance failure rates. To avoid an obstacle, a long or a short stride strategy can be used, the choice of which depends on the phase of obstacle release. There were no significant group differences in the distribution of obstacle avoidance strategies. However, the RA patients made significantly more failures when performing a short stride strategy in mid swing obstacle release trials (the condition which gave the patients the least time to react; available response time). In addition, compared to the controls, the RA group approached the obstacle more closely prior to obstacle crossing (shorter toe distance), thereby increasing the risk of stumbling.

Conclusion

Obstacle avoidance performance in persons with RA is significantly deteriorated compared to age- and gender-matched controls, especially when available response time is low. This deficit may contribute to their higher fall risk.

Key words

Obstacle avoidance, gait, rheumatoid arthritis, falls

Ellen Smulders, MSc, PT
Chantal Schreven, MSc, PT
Wim van Lankveld, PhD
Jacques Duysens, MD, PhD
Vivian Weerdesteyn, PhD, PT

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Please address correspondence to:
Dr Ellen Smulders,
Research, Development and Education,
Sint Maartenskliniek,
P.O. Box 9011, 6500GM Nijmegen,
The Netherlands.
E-mail: e.smulders@maartenskliniek.nl

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Introduction

Rheumatoid arthritis (RA) is an inflammatory autoimmune disease that affects the joints. Major complaints are pain and swelling in the affected joints, stiffness, fatigue and joint destruction (1). Retrospective studies show that fall incidence in adult RA patients is as high as in the elderly with one out of three persons falling at least once a year (2-4). Data on prospective fall incidence measurements in RA are scarce but our previous work has indicated that fall incidence is clearly increased in RA patients as compared to the elderly (5). Potential risk factors for falling in RA patients are diminished strength and proprioception, reduced postural stability and pain (1, 2, 5). Moreover, persons with RA are known to have a lower bone mineral density, which leads to an increased risk of fractures in the event of a fall (1, 6). This makes it even more important to better understand risk factors for falls in this population.

Lower extremity problems in persons with RA have been associated with altered gait patterns. In general, persons with RA have a slower walking velocity, shortened stride length, increased double stance period and decreased range of motion in all three planes of the forefoot (7-10). A study by van Leeden *et al*. showed that in patients with RA-related foot complaints, a longer disease duration causes a shift from a heel-to-toe roll-over gait to a more shuffled gait (11), which increases the propensity to trip over an obstacle. It has been shown that the ability to efficiently avoid an obstacle is reduced in elderly persons and this ability further deteriorates with advancing age, in parallel with an increased fall risk in daily life (12). When morbidity is present, one may expect further deterioration. For example, patients with pain associated with osteoarthritis of the knee have an increased probability to trip on an obstacle (13). Although the circumstances of falls in RA patients have not been described in the literature, it is known that trips and slips are the most prevalent causes of falls in the elderly population in general (accounting for 59% of falls) (14). Many of these falls are provoked by an external factor, such as an obstacle (15), and obstacle avoidance is thus an important area of investigation.

The main determinant for success in obstacle avoidance under time pressure is the Available Response Time (ART). The ART is defined as the time between obstacle detection and the estimated moment of foot contact with the obstacle. With longer ARTs, persons have enough time to react and thus will hardly ever contact the obstacle, but when ARTs become shorter, the time pressure increases and the obstacle will be hit more frequently (16-18).

The choice of obstacle avoidance strategy is a second determinant for success in obstacle avoidance. Two different strategies can be used to avoid an obstacle. In a long stride strategy (LSS) the obstacle is crossed by a lengthened stride. The other strategy is a short stride strategy (SSS) in which the stride before crossing is shortened and the obstacle is crossed in the next stride. Which strategy is most efficient to avoid an obstacle depends on the ART and the distance of the foot to the obstacle (16-19).

The aim of this study was to determine whether RA patients in general have increased difficulties with avoiding obstacles while walking. Our hypothesis was that RA patients would have higher failure rates on the obstacle avoidance task compared to healthy controls, because of the joint and mobility problems in RA patients and since they often have high pain levels. Furthermore, obstacle avoidance strategy and the distribution of failures over the different strategies will be examined along with parameters related to obstacle avoidance (heel and toe distances and reaction time).

Methods

Participants

Eligible participants were selected from a large study population included in a study on fall risk factors in persons with RA (5). This population was randomly sampled from the visitors of our rheumatology clinic, twelve patients with RA (7 female, 5 male, mean age 61 (SD 11, range 42-76 years) were included. Inclusion criterion was the diagnosis RA, according to the ACR (American College of Rheumatology) criteria (20). Participants were excluded when they were recently diagnosed with RA (< one year), had neurological disorders or were not able to walk at least 15 minutes without the use of a walking aid. None of the participants had corticosteroid injections in the articular joints in the six months prior to the study. The following data were obtained to characterize the RA patients: disease activity (Erythrocyte Sedimentation Rate), disease duration, number of affected joints, medication use, Visual Analog Scale (VAS) scores of pain during stance and walking (0=no pain, 100=severe pain) and scores on the Health Assessment Questionnaire (HAQ) (21) and Arthritis Impact Measurement Scales 2 Short Form (AIMS2-SF) (22). Furthermore, the RA patients monitored their fall incidence for one year, by means of monthly fall registration cards. In addition, 12 healthy controls of the same gender and comparable age (7 female, 5 male, mean age 61 (SD 10, range 46-78 years) were included. This study was approved by the medical ethical committee of the region Arnhem-Nijmegen and all participants gave written informed consent for participation.

Fig. 1. Experimental set up. In front of the treadmill, the obstacle is attached to a bridge with an electro-magnet. After a trigger from the computer the magnet switches off and the obstacle falls in front of the left foot of the participant.

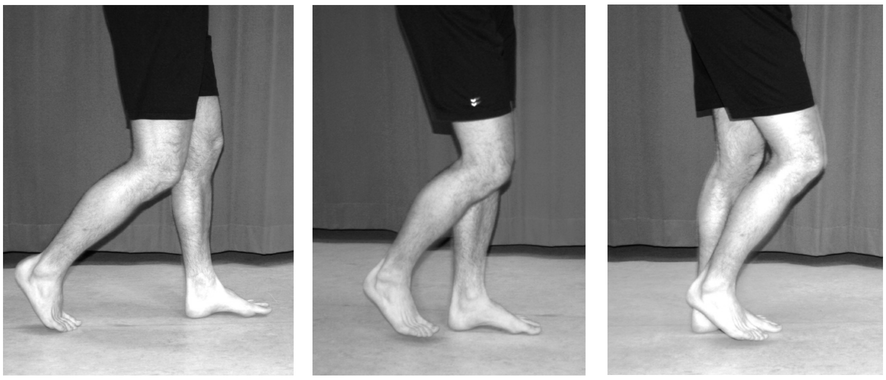

Fig. 2. Phases of the gait cycle and the three phases of obstacle release in the obstacle avoidance experiment; 1: late stance, 2: early swing, 3: mid swing.

Sample size

An *a priori* sample size calculation was performed for this study, using the data of a previous study on the same task in healthy young and older persons (23). We aimed to detect a minimal between-group difference in obstacle avoidance failure rates of 10% and used a standard deviation of 7% (23) in the sample size calculation. With a power of 0.9 and a two-tailed α of 0.05 the required number of patients per group was 12.

Experimental set-up and protocol

The participants were instructed to avoid obstacles while walking on a treadmill (ENRAF Nonius, Type ENtred Reha) at a fixed velocity of 3 km/hr, wearing comfortable shoes. This velocity was selected, because it is a comfortable walking speed for both RA patients and healthy persons (24-26). They were secured by a safety harness, attached to the ceiling. Above the front of the treadmill a bridge was placed with an electro-magnet. The obstacle (40cm [length] x 30cm [width] x 1.5cm [height]) was held by the magnet in front of the left foot. Two reflective markers were attached to the shoe on the left heel and hallux and one marker was attached on top of the obstacle. Marker positions were recorded by a 6-camera 3D motion analysis system (Vicon, 100Hz). In Figure 1 the experimental set up is presented.

Before the experiment started the participants were given an opportunity to familiarize to treadmill walking. Furthermore, five practice trials of obstacle avoidance were performed. Stepping sideways from the obstacle was not allowed. The participants walked on the treadmill at a fixed distance of 10 cm to the obstacle. For each step, the motion analysis system provided on-line information of the distance to the obstacle on the basis of the markers on the foot. When this distance systematically deviated from 10 cm over a number of steps, the experimenter instructed the participant to correct his/her distance.

During the experiment, the obstacle was released at one of three different phases of the gait cycle: late stance, early swing and mid swing, to create different levels of difficulty. Late stance obstacle release was the easiest condition, with the most time to react (long ART), whereas mid swing release represented the most difficult condition (short ART). In Figure 2 the different phases of the gait cycle in which the obstacle could be released are presented.

Each condition was repeated ten times, randomly divided over two series of 15 trials. The number of strides between two successive obstacle releases was variable so that the moment of obstacle release was not predictable.

Obstacle release was triggered by a computer, as described in detail in a previous study (12). To determine the correct moment of obstacle release the heel marker position was processed in real-time during the experiment. Algorithms were used to predict the next heel contact. Based on this information the exact timing of obstacle release in a certain phase of the gait cycle was determined. The obstacle was not released before a regular walking pattern had been achieved, which was defined as less than 50ms difference in stride duration between two consecutive strides.

The primary outcome measure was avoidance failure rate. Failures were defined as contact of the foot with the obstacle and were noted during the experiment by two observers. In the case of disagreement between the observers the 3D recordings were checked to verify whether the foot had touched the obstacle. The strategy used to avoid the obstacle (SSS or LSS) was also noted. The present study was designed such that the obstacle was released at different ARTs. Based on prior research it can be expected that in mid swing trials (short ARTs) an SSS is used in the majority of trials, whereas in the late stance obstacle release trials (long ARTs) the LSS prevails (12, 17, 27). Failures during an SSS occur because participants contact the most proximal part of the obstacle with their toes. A failure during an LSS occurs when the heel touches the distal part of the obstacle (27).

From the recording of the marker positions spatial parameters were determined. Data were obtained both on toe distance to the obstacle before obstacle avoidance and on heel distance after obstacle avoidance. Toe distance is most relevant to characterize successful SSS, whereas heel distance is most relevant for successful LSS. In addition, reaction time (RT) was derived from the marker position data. RT was defined as the time which the acceleration curve of the avoidance swing phase exceeded the mean ± 2 standard deviations of 30 control swing phases.

Data processing and statistical analyses

First, ARTs were calculated for each phase of obstacle release. To ensure that the level of difficulty of the task was indeed similar in the experimental and control group, it was checked whether the ARTs were equal in both groups. This was done by means of a repeated measures ANOVA, with 'phase' as a within subjects and 'group' as a between subjects variable.

The same statistical test was conducted to compare failure rates and strategy choice for the 3 phases of obstacle release (late stance, early swing, mid swing) between RA patients and control. Post hoc analyses were performed using Students *t*-tests (alphas corrected for multiple comparisons). To analyze whether the groups differed with respect to the number of failures in each of the strategies, a Chi-Square test was applied.

To compare toe and heel distances between the RA group and healthy controls an univariate ANOVA was used, with ART as covariant. Reaction times were analyzed by means of a Students *t*-test. The alpha level was set at 0.05.

Results

The characteristics of the RA patients are described in Table I. Mean height of the RA patients was 171 (SD 9) cm and 166 (SD 7) cm for the controls. The mean weight of the RA patients and controls was 71 (SD 12) and 82 (SD 18) kg, respectively. There were no significant differences (p<0.05) between the RA patients and the control group for gender, age, height and weight. According to their HAQ scores, the RA patients in this study were moderately affected by their disease (28).

The prospective fall incidence registration showed that the RA patients had a mean of 2.0 falls per person in one year, with 83% reporting at least one fall. The number of falls per person ranged from one to nine (24 falls in total). Most of the falls occurred during walking (61% of all falls) and 57% of these falls were caused by tripping over an obstacle. Other causes were falling down the stairs, getting off a bike, getting into bath and a failed attempt to sit down on the floor. No serious injuries occurred because of the falls. In 52% of the falls the RA patients reported bruises, in 26% pain was reported, 17% caused scrapes and in 22% no injuries occurred.

Obstacle avoidance

As expected the release in the various phases induced different ARTs (main of effect of phase (F(2,44)=1925.995, p<0.001). The mean ART was 494±28 ms for late stance phase trials, 344±27 ms for early swing and 238±19 ms for mid swing. The analysis of ARTs confirmed that the level of difficulty of the task was equal for both groups, because there was no main effect of Group (F(1,22)=0.030, p=0.865) and no interaction effect of Phase x Group (F(2,44)=1.183, p=0.316).

In Figure 3, the failure rates of the RA group and the controls are shown for each phase and for the total experiment. The failure rates increased in both groups when the trials became more challenging. In late stance the mean failure rate was 1% for the controls and 3% for the RA group, whereas in the mid swing phase, failure rates of 20% and 43% were seen for the controls and RA group respectively. RA patients were less successful than their controls, but this was dependent on the phase of obstacle release (Phase x Group interaction, F(2,44)=4.364, p=0.019).

Post hoc analysis of the failure rates in the three phases of obstacle release showed that RA patients performed significantly worse in the mid swing phase (p=0.012), but there were no significant differences between the groups in early swing (p=0.171) or late stance (p=0.336). Within the RA group, failure rates did not depend on disease severity (HAQ score) and pain during walking (VAS score), as introducing these factors as covariants in the ANOVA model did not yield significant interactions with failures rates (respectively, p=0.238 and p=0.332).

With regard to the strategy choice and failures, as expected, it was found that in mid swing (short ARTs) the SSS was used in the majority of trials, whereas in the late stance (long ARTs), the LSS prevailed (see Fig. 3). Statistical analysis confirmed that the strategy used to avoid the obstacle differed between the phases of obstacle release (main effect of Phase, F (2,44)=73.236, p<0.001). Overall, the distribution of avoidance strategies changed from predominantly LSS (98%) in late stance trials to pre-

Table I. Patients' characteristics (n=12).

Disease activity (n)		
High erythrocyte sedimentation rate (>25 mm/u)	3	
High C-reactive protein (>5 mg/l)	1	
Mean disease duration (months (SD, range))	161	(151, 30-444)
Mean number of affected joints* (SD, range,)	8	(5, 3-17)
Affected joints (n):		
Hand (left-right)	10:11	
Wrist (left-right)	5:8	
Elbow (left-right)	3:4	
Shoulders (left-right)	6:6	
Forefoot/toes (left-right)	10:11	
Heel (left-right)	2:2	
Ankle (left-right)	4:3	
Knee (left-right)	5:3	
Hip (left-right)	1:2	
Neck	2	
Lower back	1	
VAS pain during stance (mm (SD, range))	40	(24, 3-78,)
VAS pain during walking (mm (SD, range))	44	(28, 5-80)
HAQ (mean (SD, range))	1.1	(0.6, 0.0-2.1)
AIMS2-SF (mean (SD, range))	5.8	(1.2, 4.0-8.2)
Medication (n.):		
Paracetamol	7	
NSAIDs	10	
DMARDs	10	
Biologicals	2	
Corticosteroids	2	
Orthopaedic surgery in lower extremities (n)	2	

*Affected joints are defined as joints that the RA patient reported to be warm, tender, swollen and/or painful.

dominantly SSS (70%) in mid swing trials. The RA group and the controls had similar proportions of LSS and SSS in each of the phases of obstacle release.

The remaining question is whether the increased failure rate of the RA patients depends on the avoidance strategy used. In Figure 4 the percentage of successful trials and failures is shown for each strategy and phase. It can be seen that the difference between the RA patients and controls resides primarily in the percentage of failures in the SSS, in particular during the mid swing phase (when there was a significant difference between the RA patients and the controls in avoidance failure rates). Indeed, RA patients had significantly more failures during SSS in the mid swing phase ($\chi^2(1)=18.633$, $p<0.001$) compared to their controls. For LSS trials the groups showed no differences in the number of failures ($\chi^2(1)=0.197$, $p=0.657$).

Kinematic data were also obtained. RA patients had significantly smaller toe distances than the controls (24.8±6.6 *vs.* 79.4±10.3 mm, $p=0.026$). Heel distances did not differ between the groups ($p=0.830$). The reaction time of the RA patients was higher compared to the healthy controls, but this difference was not significant (166±25 *vs.* 150±17 ms, $p=0.093$).

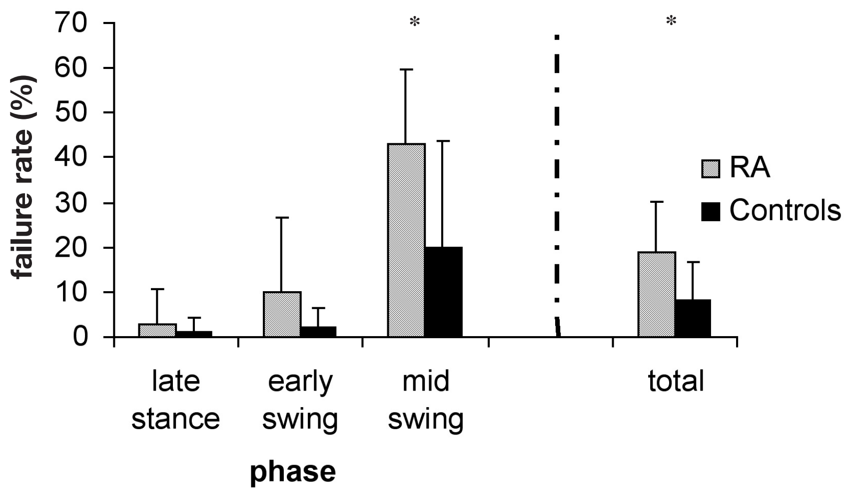

Fig. 3. Mean values and standard deviations of the failure rates of RA patients and controls in the three phases of obstacle release and in total. The asterisk indicates a significant difference between the groups ($p<0.05$).

Discussion

The aim of this study was to determine whether RA patients would have more problems with avoiding obstacles compared to healthy controls, which may expose them to an increased risk of falling. Our hypothesis was that obstacle avoidance would be deteriorated in patients with RA compared to healthy controls. The results of our study confirm this hypothesis. The RA patients had higher failure rates on the obstacle avoidance task compared to the healthy controls. This was mainly due to the most difficult condition (mid swing phase) when the ARTs were short. These findings are in line with earlier studies that showed that mobility problems are associated with increased obstacle avoidance failure rates (13, 29, 30). The finding that in late stance and early swing conditions no significant group differences were observed may well be due to the small sample size. The average failure rates for these phases of obstacle release were also higher in the RA group than in the controls, but the between-group differences were smaller than in the mid-swing condition.

A possible reason for the higher failure rates in the RA group could have been a different preference of obstacle avoidance strategy. In other studies it was shown that elderly persons, compared to younger controls, prefer the LSS

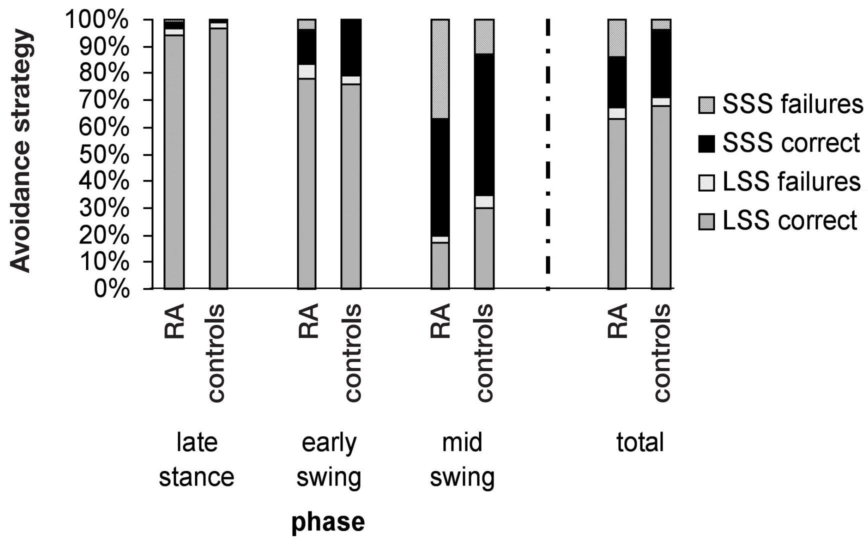

Fig. 4. Distribution of successful and failed trials for the short stride strategy (SSS) and long stride strategy (LSS) for the RA patients and their controls. Results are shown for each phase of obstacle release and in total.

(12). This was also seen in patients with pathologies such as a stroke or a lower extremity amputation compared to healthy controls (29, 30). However, contrary to the findings in these studies, there were no differences in distribution of the obstacle avoidance strategies between the RA patients and their controls.

A less efficient choice of obstacle avoidance strategy can therefore not be the reason for the significantly higher failure rates of the RA patients. However, failures were not equally distributed over both strategies. In the mid swing phase, RA patients made significantly more failures during an SSS, whereas the number of LSS failures was not different between patients and controls. Of all the SSS strategies in the mid swing phase RA patients failed 48%, whereas the controls only failed 17% of the SSS trials. A failure during an SSS occurs when the step is not appropriately shortened and the participant touches the obstacle with the forefoot. Not only did the RA patients make more failures during an SSS in the mid swing phase, they also had significantly smaller toe distances to the obstacle when they performed a correct SSS. This means that they were at greater risk of touching an obstacle.

Why would the RA patients have special difficulties in executing an SSS? One reason could be that RA patients are slower in these reactions. The time to landing is much shorter in an SSS than in an LSS. Hence, if there is a delay in response this will have much more consequences for the SSS. Delayed obstacle avoidance reaction times and reduced response amplitudes are indeed related to higher obstacle avoidance failure rates (23). There is some indirect evidence indicating that RA patients have delayed reaction times and reduced speed of movement. Kauranen *et al.* (31) suggested that because of motor unit problems, destructive and inflammatory changes in the joints and pain or fear of pain, patients with RA avoid performing fast movements as quickly as normal. However, they only studied hand movement and reaction times. The RA patients in this study showed an increase in reaction time of 16 ms compared to the controls. However, this difference was not significant, presumably due to high intersubject variability, low sample size or heterogeneity of the RA group.

A limitation of the study is that walking on a treadmill with a fixed walking speed is not the same as overground walking. However, previous studies have shown that the differences between these walking conditions are minor (32). The mechanics of treadmill walking were not different from those of overground locomotion, as long as the treadmill speed was held constant (33). Furthermore, for obstacle avoidance it was shown that the same strategies are used in overground studies as in treadmill ones (13). In addition, treadmill walking allows for a much better control of walking speed. For these reasons our group has used a treadmill design in several studies (12, 17, 23, 27). The present experiment used exactly the same methods, thereby allowing comparison with these previous studies.

A second limitation concerns the group size. Because poor obstacle avoidance can distinguish fallers from non-fallers in healthy elderly (17), it would have been of interest to examine the relationship between failure rate and falls in this group. However, our group size was not large enough to identify differences in obstacle avoidance performance between the RA patients who reported a fall in the year they monitored their fall incidence and those who did not. Nonetheless, it was shown that most of the falls in the one year follow-up occurred during walking (61%), with tripping over obstacles as a frequent cause, which may indicate that poor obstacle avoidance during walking is a risk factor for falling. Because of the small sample size it was also not possible to discriminate between subpopulations within the rather heterogenic RA group. Various RA-related factors may affect the ability to avoid obstacles while walking. The patient(s) with orthopaedic surgery of the lower extremity joints, high pain scores, high disease activity, longer disease duration or large numbers of affected joints, however, did not represent outlying values on the obstacle avoidance failure rates of the RA group in this study. Further research is needed to identify the critical determinants for the impaired obstacle avoidance performance of the RA patients.

In conclusion, RA patients are less successful in obstacle avoidance than healthy controls, which may put them at increased risk for falling. In order to design appropriate intervention strategies to prevent falls and fall-related fractures in persons with RA, further research of the reasons why RA patients are less successful in avoiding obstacles is required. Such investigations can help in understanding the contribution of this poor obstacle avoidance and other risk factors to the relatively high fall incidence rates in persons with RA.

References

1. LANE NE, PRESSMAN AR, STAR VL, CUMMINGS SR, NEVITT MC: Rheumatoid arthritis and bone mineral density in elderly women. The Study of Osteoporotic Fractures Research Group. *J Bone Miner Res* 1995; 10: 257-63.
2. ARMSTRONG C, SWARBRICK CM, PYE SR, O'NEILL TW: Occurrence and risk factors for falls in rheumatoid arthritis. *Ann Rheum Dis* 2005; 64: 1602-4.
3. JAMISON M, NEUBERGER GB, MILLER PA: Correlates of falls and fear of falling among adults with rheumatoid arthritis. *Arthritis Rheum* 2003; 49: 673-80.
4. TINETTI ME, DOUCETTE J, CLAUS E, MAROTTOLI R: Risk factors for serious injury during falls by older persons in the community. *J Am Geriatr Soc* 1995; 43: 1214-21.
5. SMULDERS E, SCHREVEN C, WEERDESTEYN V, VAN DEN HOOGEN FHJ, LAAN R, VAN LANVELD W: Fall incidence and fall risk factors in persons with rheumatoid arthrtitis, *Ann Rheum Dis* 2009; 68: 1795-6.
6. LODDER MC, DE JONG Z, KOSTENSE PJ *et al.*: Bone mineral density in patients with rheumatoid arthritis: relation between disease severity and low bone mineral density. *Ann Rheum Dis* 2004; 63: 1576-80.
7. WOODBURN J, NELSON KM, SIEGEL KL, KEPPLE TM, GERBER LH: Multisegment foot motion during gait: proof of concept in rheumatoid arthritis. *J Rheumatol* 2004; 31: 1918-27.
8. LAROCHE D, ORNETTI P, THOMAS E, BALLAY Y, MAILLEFERT JF, POZZO T: Kinematic adaptation of locomotor pattern in rheumatoid arthritis patients with forefoot impairment. *Exp Brain Res* 2007; 176: 85-97.
9. O'CONNELL PG, SIEGEL KL, KEPPLE TM, STANHOPE SJ, GERBER LH: Forefoot deformity, pain, and mobility in rheumatoid and nonarthritic subjects *J Rheumatol* 1998; 25: 1681-6.
10. TURNER DE, HELLIWELL PS, SIEGEL KL, WOODBURN J: Biomechanics of the foot in rheumatoid arthritis: Identifying abnormal function and the factors associated with localised disease 'impact'. *Clin Biomech* (Bristol, Avon) 2008; 23: 93-100.
11. VAN DER LEEDEN M, STEULTJENS M, DEKKER JHM, PRINS APA, DEKKER J: The relationship of disease duration to foot function, pain and disability in rheumatoid arthritis patients with foot complaints. *Clin Exp Rheumotol* 2007: 25: 275-80.
12. WEERDESTEYN V, NIENHUIS B, DUYSENS J: Advancing age progressively affects obstacle avoidance skills in the elderly. *Hum Mov Sci* 2005; 24: 865-80.
13. PANDYA NK, DRAGANICH LF, MAUER A, PIOTROWSKI GA, POTTENGER L: Osteoarthritis of the knees increases the propensity to trip on an obstacle. *Clin Orthop Relat Res* 2005; 150-6.
14. BERG WP, ALESSIO HM, MILLS EM, TONG C: Circumstances and consequences of falls in independent community-dwelling older adults. *Age Ageing* 1997; 26: 261-8.
15. TINETTI ME, SPEECHLEY M, GINTER SF: Risk factors for falls among elderly persons living in the community. *N Engl J Med* 1988; 319: 1701-7.
16. CHEN HC, ASHTON-MILLER JA, ALEXANDER NB, SCHULTZ AB: Age effects on strategies to avoid obstacles. *Gait Posture* 1994; 2: 136-46.
17. WEERDESTEYN V, NIENHUIS B, MULDER T, DUYSENS J: Older women strongly prefer stride lengthening to shortening in avoiding obstacles. *Exp Brain Res* 2005; 161: 39-46.
18. PATLA AE, PRENTICE SD, RIETDYK S, ALLARD F, MARTIN C: What guides the selection of alternate foot placement during locomotion in humans. *Exp Brain Res* 1999; 128: 441-50.
19. MORAES R. LEWIS MA, PATLA AE: Strategies and determinants for selection of alternate foot placement during human locomotion: Influence of spatial and temporal constraint. *Exp Brain Res* 2004; 159: 1-13.
20. ARNETT FC, EDWORTHY SM, BLOCH DA *et al.*: The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. *Arthritis Rheum* 1988; 31: 315-24.
21. BOERS M, JACOBS JW, VAN VLIET VLIELAND TP, VAN RIEL PL: Consensus Dutch health assessment questionnaire. *Ann Rheum Dis* 2007; 66: 132-3.
22. TAAL E, RASKER JJ, RIEMSMA RP: Psychometric properties of a Dutch short form of the Arthritis Impact Measurement Scales 2 (Dutch-AIMS2-SF). *Rheumatology* 2003; 42: 427-34.
23. WEERDESTEYN V, NIENHUIS B, GEURTS AC, DUYSENS J: Age-related deficits in early response characteristics of obstacle avoidance under time pressure. *J Gerontol A Biol Sci Med Sci* 2007; 62: 1042-7.
24. PERRY J: Gait analysis- Normal and Pathological Gait. Thorofare, NJ, Slack Incorporated, USA, 1992.
25. ESCALANTE A, HAAS RW, DEL RINCON J: Measurement of global functional performance in patients with Rheumatoid Arthritis using rheumatology function tests. *Arthritis Res Ther* 2004; 6: R312-25.
26. LAROCHE D, ORNETTI P, THOMAS E, BALLAY Y, MAILLEFERT JF: Kinematic adaptation of locomotor pattern in rheumatoid arthritis patients with forefoot impairment. *Exp Brain Res* 2007; 176: 85-97.
27. WEERDESTEYN V, SCHILLINGS AM, VAN GALEN GP, DUYSENS J: Distraction affects the performance of obstacle avoidance during walking. *J Mot Behav* 2003; 35: 53-63.
28. BRUCE B, FRIES JF: The Health Assessment Questionnaire. *Clin Exp Rheumotol* 2005; 23 (Suppl. 39): S14-S18.
29. DEN OTTER AR, GEURTS AC, DE HAART M, MULDER T, DUYSENS J: Step characteristics during obstacle avoidance in hemiplegic stroke. *Exp Brain Res* 2005; 161: 180-92.
30. HOFSTAD CJ, VAN DER LH, NIENHUIS B, WEERDESTEYN V, DUYSENS J, GEURTS AC: High failure rates when avoiding obstacles during treadmill walking in patients with a transtibial amputation. *Arch Phys Med Rehabil* 2006; 87: 1115-22.
31. KAURANEN K, VUOTIKKA P, HAKALA M: Motor performance of the hand in patients with rheumatoid arthritis. *Ann Rheum Dis* 2000; 59: 812-6.
32. RILEY PO, PAOLINI G, DELLA CROCE U, PAYLO KW, KERRIGAN DC: A kinematic and kinetic comparison of overground and treadmill walking in healthy subjects. *Gait Posture* 2007; 26: 17-24.
33. VAN INGEN SCHENAU GJ: Some fundamental aspects of the biomechanics of overground versus treadmill walking. *Med Sci Sports Exerc* 1980; 12: 257-61.