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Stepping strategy used to recover balance during an induced fall is associated with impaired function and strength in people with knee osteoarthritis

Short title: Balance recovery stepping strategy in people with knee osteoarthritis

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Competing interests

The authors declare no conflict of interest

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Abstract

Aim: We investigated differences in function, strength, and pain in those with knee OA who responded with a single step compared to multiple steps during balance recovery during an induced forward fall.

Method: The stepping response of 24 participants with knee OA (50% females, age 68.6 ± 6.2 years) as they recovered balance from an induced forward fall was recorded. Participants were grouped based on their stepping response as single-stepper and multi-stepper.

Comparison was made between the groups for functional and strength tests and self-reported pain, function, quality of life, fear of falls and physical activity.

Results: Fourteen of the participants (58%) responded with a multiple-step response. Multiple steppers demonstrated greater time for the up and go ($p = 0.01$), the stair climb tests ($p = 0.05$), as well as reduced distance during the 2 min walk test ($p = 0.001$) and reduced isokinetic knee extension strength ($p = 0.02$).

Conclusion: Those who demonstrated multiple steps response had impaired function, reduced strength and were less physically active. Given the high prevalence of falls in people with knee OA, further studies are required to better understand the ability of people with knee OA to respond and avoid falls.

Introduction

Falls are the leading cause of mortality and morbidity in people aged 65 years and over^{1,2} with an estimated 30% of community dwelling adults reporting one or more falls each year³⁻⁶. Chronic musculoskeletal conditions in the lower extremities, particularly arthritis, have been shown to be independent risk factors for falls⁷⁻⁹ with approximately 50% of people with osteoarthritis (OA) over the age of 60 reporting one or more falls in a 12 month period^{10,11}.

Impairments to gait function combined with lower extremity muscle weakness and impaired balance are risk factors for falls¹². Older people with knee OA are at even greater risk of falls due to muscle weakness, reduced proprioception and balance dysfunction¹³. The

increasing prevalence of OA highlights the need for research targeting older adults with knee OA¹³.

Impaired balance is one of the main causes of falls¹⁴, and the ability to recover balance following a tripping-related perturbation is critical to avoiding a fall. One strategy for maintaining balance is to employ compensatory stepping. Older adults not only demonstrate less capacity to recover balance compared to young adults but also recover using multiple compensatory steps^{15,16}. Multiple step recovery has been shown to predict falls¹⁷ because effective recovery-step reactions and stability control are dependent on musculoskeletal capacity, sensory function and neural processing^{18,19}. While older adults' capacity to execute an effective stepping reaction is affected by ageing-related sensio-motor abilities, recovery from unanticipated balance loss might be further compromised by knee OA due to the associated physiological and neuromuscular impairments²⁰.

Despite the high prevalence of falls in people with knee OA, it has yet to be demonstrated experimentally how knee OA affects the mechanics of balance recovery. In this study we investigated the differences in function, strength, and pain between people with knee OA who responded to balance loss using a single recovery step and those who responded with multiple steps. Given that a trip-related fall can result from improper stepping response, understanding the differences in muscle strength and physical function between those who respond with a single step vs multistep can provide important information about amendable factors to be targeted for falls prevention interventions. Balance recovery from an induced forward balance perturbation was investigated using a Tether Release method by which in experimentally well-controlled conditions participants could safely experience significant unanticipated forward balance loss and their recovery responses precisely measured²¹.

Methodology

Twenty four participants with clinical symptoms of knee OA (50% females, mean \pm SD age 68.6 ± 6.2 years, height 1.7 ± 10 m, mass 80.7 ± 14.5 kg and body mass index (BMI) of 27.7 ± 4.1 kg/m²) were recruited. Knee OA was classified according to the American College of Rheumatology criteria²². To be included in the study participants had to meet the following criteria: (1) be aged ≥ 60 years, (2) reported having pain for a period over six months accompanied by stiffness and limited movement in the knee, (3) report knee pain on most days of the month, (4) report a minimum average pain score of 4 on an 11-point

numerical rating scale in the past week (where 0 is no 'no pain' and 10 is 'worst pain possible'), (5) be able to walk at least 45 m independently, and (6) with no uncontrolled systemic disease, or a pre-existing neurological or other orthopaedic condition affecting lower limb function. Patients with knee OA were recruited via advertisement in a local newsletter. All participants were fully informed about the nature of the study and signed a consent form prior to participation. The study protocol was approved by the Human Research Ethics Committee of Victoria University.

Participants underwent balance recovery tasks and the following functional and strength tests; timed up and go, four square step test, two minute walk test, stair climbing test, proprioception test, balance test and Isokinetic dynamometer. Participants also completed health related quality of life questionnaires to assess pain, function, quality of life, fear of falls and physical activity.

Balance recovery from a forward induced fall.

A previously described Tether-Release apparatus was used to induce a forward fall¹⁶. Participants wore comfortable everyday shoes and a safety harness secured overhead to allow unrestricted movement to perform the testing protocol but in the event of total loss of balance prevent falling. Three force plates (One of AMTI model BP600900TT, Watertown, MA, USA and two of AMTI model BP508600TT, Watertown, MA, USA; 1000Hz) were located in the data collection area to record ground reaction forces and to identify key events of the recovery step response. Each forward leaning position at approximately 20% of body weight was recorded using a force transducer placed in series with a horizontal restraining cable. Previous research has shown a forward leaning position corresponding to a 20% body weight to differentiate between single and multi-step responders²³. Participants were instructed to relax their muscle while leaning forward and to regain balance with a single step using the stepping leg of their choice once the restraining cable is released. One practice trial at a lean angle with 10% body weight was given followed by three testing trials at 20% body weight. Once 20% of the participant's weight was registered on the horizontal force transducer the forward perturbation was initiated via randomly timed disconnection of power to an electromagnet connected to the restraining cable (Figure 1). The first trial is likely to be a better representation of real world scenarios in which significant balance disturbance is an unanticipated event²⁴ and was accepted for analysis. **Cochran's Q test indicated no differences in the proportion between the two step responses (single vs multi) across the three recorded trials ($\chi^2(2) = 0.88, p = 0.64$).** The classification of "single stepper" and

“multiple steppers” was made using criteria similar to Carty et al ²⁵ where any second step of the stepping limb or anterior progression of the non-stepping foot past the stepping foot following its initial step was classified as multiple step. The responding leg (right/left) was also recorded.

Functional and strength tests

Knee strength and proprioception measures

Maximal voluntary isometric and isokinetic knee extension strength was measured for the responding leg of the balance recovery using an isokinetic dynamometer (Biodex multi joint system II). Knee strength of the responding leg was assessed while sitting with the hip at approximately 70° of hip flexion with the participant’s upper body, hips and thigh strapped to reduce body movement. The participants were given two practice trials for each speed, with one minute rest. Participants were asked to perform two maximal isokinetic contractions at 90°s⁻¹ and 180°s⁻¹, with 60 s recovery between sets and three isometric contractions (0°s⁻¹) at 120° knee flexion. The highest value of each set was defined as the peak torque. Knee strength scores were normalised to the participant’s height and body weight to account for differences in body size using the formula:

$$\text{normalised strength} = \frac{\text{strength (Nm)}}{[\text{height (m)} \times \text{bodyweight (N)}]} \times 100$$

Knee proprioception was measured during sitting by matching the position of the legs on either side of a clear plastic sheet with eyes closed ¹¹. Any error in matching the limbs was recorded in degrees. After 2 practice trials, the average of 5 trials was recorded.

Function and balance tasks

The following functional and balance tasks were assessed:

(1) Timed up and go test – participants required to stand up from a chair, walk 3 meters as quickly and safely as possible, cross a line marked on the floor, turn around and walk back and sit down ²⁶. The time taken to complete the task was measured with a stopwatch. One practice trial was given followed by two test trials. The best score was used in the analysis.

(2) The two min walk test was used to assess exercise tolerance ²⁷. Participants were asked to walk overground as far as possible in 2 minutes. A 10 meter pathway was marked and participants had to walk back and forth on a straight path for 2 minutes.

(3) The Four Square Step Test (FSST) was used to measure rapid dynamic weight shift and stepping²⁸. Participants were required to step as fast as possible into 4 squares marked on the floor (labelled 1-4) in a given sequence (starting from square 1 followed by 2,3,4,1,4,3,2 and 1). This sequence requires the participant to step forward, backward, and sideways to the right and left. One practice trial was given followed by a test trial. The score was time taken to complete the sequence.

(4) Functional Reach is a measure of dynamic bilateral stance reach performance²⁹. Participants were asked to extend their right arm horizontally (approximately 90⁰) and then reach as far forward as they can without losing their balance or taking a step. Each participant was given 2 practice trial and three test trials. The score was defined as the difference between the initial position and the maximal reach distance. The best score was used for analysis.

(5) A Stair Climb test was used as an objective measure of ambulatory functional limitation which involves ascending and descending an isolated set of stairs³⁰. The time required for participants to ascend and descend 5 steps was recorded.

(6) Postural sway was measured using a “Swaymeter” that recorded medio-lateral (M/L) and anterior posterior (A/P) sway while standing on a medium density foam rubber mat (70 x 60 x 15 cm thickness) with the eyes open and closed. The total excursion of the sway in each direction was measured to the nearest millimetres³¹.

Health related quality of life questionnaires

Joint pain and function - Self-reported physical function, stiffness and pain of the participants were assessed using the Western Ontario and McMaster University Osteoarthritis Index (WOMAC)³². The WOMAC is a self-assessed disease-specific measure of patients with osteoarthritis of the knee which assesses the severity of the knee pain during 5 daily activities and the severity of impairment of lower-extremity function during 17 activities. The items are scored with the use of a 10cm visual analogue scale, where 0 represents no pain or difficulty with physical function with higher scores representing worse functional health.

Physical activity questionnaire - The Incidental And Planned Activity Questionnaire (IPAQ) for older people was used to assess the physical activity level of the participants³³. The IPAQ includes 10 questions that estimates the physical activity on an average week in

the past 3 months and covers the frequency and duration of planned activity (planned exercise and walking) and incidental activities (casual day-to-day activities). The score was derived from multiplying frequency score and duration score to create a total duration for incidental and planned activity as well as an overall total score. Total time spent was summed across all components and expressed as hours per week as detailed in Delbaere et al³³.

The falls efficacy scale (Short FES-I) questionnaire was used to record the fear of falling³⁴. The FES-I consists of 7 items on Likert scale that score the participant's level of concern regarding the possibility of falling when performing certain daily activities. The total score ranges from 7 (not concerned) to 28 (severe concern)³⁴.

Quality of life (QoL)– Quality of life was measured using the self-administered Assessment of Quality of Life (AQoL) utility instrument, which assesses quality of life over five domains including illness, independent living, social relationships, physical senses and psychological well being³⁵. The utility score for each dimension and an overall utility score range from 0 and 1, where 0 represents the worst health and 1 represents perfect health.

Previous falls history

The number of falls the participants experienced in the preceding 12 months was recorded.

Statistical analysis

Analysis of variance with Bonferroni-adjusted post-hoc tests were used to assess the differences between single steppers and multiple steppers for the following variables: knee strength and proprioception, functional and balance tests and health related quality of life questionnaires. The non-parametric Kruskal-Wallis test was used to compare between the groups for the proprioception test as the values were ordinal. Differences in participants demographics (age, height, mass, BMI) were assessed using independent t-tests. Chi-square tests were used to compare the differences in the number of falls and gender between single steppers and multiple steppers. All statistical analyses were performed using IBM SPSS Version 20 (SPSS Inc, Chicago, IL, USA) and a p value less than 0.05 was considered statistically significant.

Results

Participants' demographic data is presented in Table 1. Ten participants (42%) responded with a single step response while 14 (58%) utilised multiple steps response. No significant differences were found for age or BMI between single steppers and the multiple

steppers ($p > 0.05$; Table 1). Nine participants (64.3%) from the multiple steppers reported at least one fall in the previous 12 months compared to 40% among the single steppers ($p = 0.16$). The number of females was significantly ($p = 0.04$) greater in the multiple steppers compared (64.3%) to the single steppers group (30%). Sixty percent of the single stepper and 50% of the multiple steppers used their unaffected leg to initiate step.

Multiple steppers demonstrated a greater time for the up and go test (7.5 ± 1.1 and 6.4 ± 0.7 s; $p = 0.01$) and the stair climb test (8.3 ± 3.0 and 6.5 ± 1.0 s; $p = 0.05$) and reduced distance during the 2 min walk test (153.1 ± 18.7 and 185.5 ± 24.9 m; $p = 0.001$) as shown in Table 2. Significantly reduced strength was also demonstrated for the multiple steppers during the isokinetic knee extension strength test at 180°s^{-1} (3.5 ± 1.4 and 4.8 ± 1.0 %BW *Height ; $p = 0.02$) with no significant differences in the other isokinetic knee extension velocity or isometric tests ($p > 0.05$). No significant differences were found in the other functional or balance tests (Table 2).

No significant differences were found in the quality of life, fear of falls, WOMAC subscales of pain, function and stiffness or the overall score (Table 2). However, the single steppers reported spending significantly greater time doing planned physical activity ($p = 0.01$).

Discussion

People with knee OA have approximately 2.5 times the risk of falling compared to community dwelling older adults who do not have knee OA^{10,11,36}. Several risk factors have been suggested to contribute to the increased risk of falling in this group but the underlying mechanism remains unclear. The ability to recover balance from a perturbation was hypothesised to assist in better understanding the physiological factors associated with falls in people with knee OA. This study found that 58% of the participants responded with a multiple-step response when required to recover balance from an induced forward perturbation. More females responded with a multiple step response compared to males. Moreover, the multiple steppers demonstrated impaired function, reduced strength and were less physically active compared to the single-steppers.

The capacity to employ adaptive stepping responses to maintain balance following a significant perturbation is an essential biomechanical response to prevent falling. A rapid

compensatory step assists in maintaining balance by generating muscle torque at the lower limb joints. Such a task requires a coordinated neuromuscular control which may be reduced in older people³⁷. Previous reports indicate that multiple step balance responses by older people predict future falls²⁵. In the present study, for the specific perturbation tested, 58% of the participants responded with a multiple-step response consistent with previous reports (50%-61%)^{16,38}. Moreover, similar to a previous report, a greater proportion of females recovered with a multiple step response³⁹. Furthermore, 64% of the multi steppers had sustained at least one fall in in the preceding year, compared to only 40% of the single steppers. While this difference was not significant the relatively high number of fallers in the multi steppers group might suggest a link between the stepping response strategy and the participants' falls history. Given the cross sectional study design employed here, however, a causal relationship cannot be inferred and prospective studies are required to confirm this association.

Pain has been reported as an important risk factor for falls where half of older adults with pain reported one or more falls in the past 12 months compared to older adults without pain⁴⁰. Musculoskeletal knee pain, such as in knee OA, may predispose to falls as it contributes to muscle weakness and mobility limitation⁴¹. However, the location of pain in the lower limb and the association with falls has been reported to be inconsistent, suggesting that knee pain might be associated with increased risk of falls predominantly when the pain is severe or chronic⁴⁰. In the present study no difference in pain was observed for the multi steppers compared to the single steppers, while differences existed on several functional tests. The pain level as determined by WOMAC varied between the participants and ranged from mild to moderate.

Despite no differences in pain, multi steppers showed reduced function in the timed up and go test, 2 min walk test and stair climbs. These functional tests measure ambulatory functional limitation and suggest greater disability and impairment in the multi steppers. Interestingly, the static balance measures did not differ between the groups. Given the dynamic balance response needed during the induced forward fall, the static balance tests might not be relevant to detect differences during dynamic situations between the groups⁴².

Muscle weakness is another important risk factors for falls⁴³. People with knee OA often demonstrate reduced quadriceps muscle strength⁴⁴. In the present study the multi steppers showed reduced isokinetic quadriceps strength at a speed of 180°s⁻¹ compared to the single steppers but no significant differences in muscle strength were observed at other

speeds. A strong trend, however was observed for reduced isometric knee strength for the multi steppers ($p = 0.06$). The ability to recover balance requires rapid reaction where both strength and speed are important to prevent a fall; it might therefore explain why differences were observed at the highest speed of quadriceps muscle strength. In a recent study, knee extension strength was found to predict a multi-step strategy during an induced forward fall, indicating older adults with weaker knee extensors had greater difficulty and adopted a multi-step recovery²⁵. Consequently, quadriceps strength is important for stability control where the muscle is required to generate joint power for adequate dynamic stability during a balance disturbing situation to arrest a fall³⁸. It is also important to note that muscle weakness around the hip and ankle might also play a role in contributing to falls. Given that neuromuscular deficit, especially quadriceps weakness, is prominent in knee OA, it may contribute to the high rate of falls experienced in people with knee OA.

Physical activity, falls and fear of falling have a complex relationship. Physical activity is required to provide neuromuscular functioning that is necessary to maintain balance and to react to prevent a fall. However, a higher level of physical activity may also imply a greater exposure to environmental hazards which can potentially lead to a fall⁴⁵. Fear of falling is also a factor contributing to reduced physical activity in older people as it has been recognised as a common problem in older people and in those with lower limb arthritis, with serious consequences in relation to loss of confidence, reduced activity and loss of independence^{46,47,48}. Pain may also increase older adult's risk of developing fear of falling and avoiding activities due to fear of falling⁴⁹. Given the suggested interaction between fear of falling and pain and that no differences in pain were found, it may explain the lack of significant difference in fear of falling between multiple and single steppers. However, a prospective study is required to further examine such relationship. We found that multiple steppers were significantly less physically active but had a similar (mild) fear of falling score when compared to single steppers. Moreover, both groups showed similar level of daily activities (incidental activities). Consequently, the increased level of planned physical activity in the single steppers might explain the increased muscle strength and better functional outcomes demonstrated by this group. Given the beneficial effect of exercise intervention for falls prevention, being more physically active might provide a preventative effect on falls.

While this study provides useful information to better understand falls in people with knee OA, several limitations are acknowledged. Firstly, a significant disparity in gender between the two groups was present where more females responded in multiple steps.

However due to the relatively small sample size a comparison between the genders could not have been performed. Future studies with a larger sample size of people with knee OA are needed to compare the balance response between the genders as well as people with different pain levels. Moreover, the results of the study are relevant for the present group with knee OA who had mild pain level (as indicated by the WOMAC). However, the recovery step response might be different for patients with higher reported pain level or different level of OA severity. In the present study the use of psychotropic drugs has not been controlled or recorded, however given the possible influence of psychotropic drugs on balance performance⁵⁰, this should be recorded. Lastly, falls in older people usually result from an interaction of multiple factors, both extrinsic (environmental) and intrinsic (individual-related). In this study we investigated the response of people with knee OA during a forward induced fall which is mainly related to falls associated with balance loss. While balance loss is one of the most common causes for fall, other causes may also contribute to the increased risk of falls in people with knee OA and requires further investigations. Further research is also required to investigate the mechanism associated with falls during forward fall scenarios to better understand the ability of people with knee OA to respond to avoid falling and the neuromuscular changes that contribute to dynamic balance deficits

Conclusion

Multiple steps balance response during an induced forward fall may be predictive of future falls. In the present study, approximately 60% of the participants with knee OA responded with a multiple-steps response while recovering balance from an induced forward fall. Multiple steppers demonstrated impaired physical function, reduced isokinetic knee strength and were less physically active compared to the single steppers. Given the high prevalence of falls in people with knee OA, further studies are required to better understand the ability of people with knee OA to respond to a falls 'challenge' and the neuromuscular changes that contribute to dynamic balance deficits. This may offer a potential target for falls prevention in this population.

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Figure legend

Figure 1: The Tether-Release method of balance recovery from an induced forward fall. Participants were placed in a forward lean angle with an horizontal force transducer. An electromagnet was connected to a restraining cable which was randomly disconnected once forward perturbation was initiated.

Table 1: Participant characteristics, values reported as mean \pm standard deviation.

Parameters	Single steppers (n=10)	Multiple steppers (n=14)	P value
Age (yr)	66.8 \pm 5.7	70 \pm 6.5	0.22
Gender % F(n)	30% (3)	64.3% (9)	0.04*
Height (m)	1.7 \pm 0.1	1.6 \pm 0.1	0.23
Body mass (kg)	77.8 \pm 13.5	82.8 \pm 15.3	0.41

Body mass index (kg/m ²)	26.1 ± 2.3	28.9 ± 4.7	0.09
Responding leg: affected % (n)	40% (4)	50% (7)	---
Falls in previous 12 months % (n)	40% (4)	64.3% (9)	0.16

*Significant level $p < 0.05$

Table 2: Differences in function, strength and health related quality of life measures between single steppers and multiple steppers.

Parameters	Single steppers (n=10)	Multiple steppers (n=14)	P value
Functional and balance tests			
Timed up and go (s)	6.4 ± 0.7	7.5 ± 1.1	0.01*
2- min walk test (m)	185.5 ± 24.9	153.1 ± 18.7	0.001*
FFST (s)	7.15 ± 1.1	8.1 ± 1.1	0.06
Functional Reach (cm)	29.6 ± 5.6	31.5 ± 4.5	0.37
Stair climb(s)	6.5 ± 1.0	8.3 ± 3.0	0.05*
Postural sway M/L-eyes open (mm)	19.7 ± 13.9	21.7 ± 9.8	0.68
Postural sway A/P-eyes open (mm)	18.7 ± 9.9	20.0 ± 7.3	0.71

Postural sway M/L – eyes closed (mm)	40.1 ± 29.4	30.9 ± 13.5	0.31
Postural sway A/P- eyes closed (mm)	42.9 ± 12.2	45.1 ± 15.4	0.70
Strength and proprioception			
†Isokinetic Knee strength 90°s ⁻¹	6.2 ± 1.9	5.0 ± 2.5	0.21
†Isokinetic Knee strength 180°s ⁻¹	4.8 ± 1.0	3.5 ± 1.4	0.02*
†Isometric Knee strength 120°	8.4 ± 1.4	6.8 ± 2.1	0.06
Proprioception	2.2±1.4	1.8±0.7	0.31
Health related quality of life			
AQoL	0.7 ± 0.1	0.7 ± 0.1	0.84
IPAQ total	31.8±15.4	26.1±17.3	0.41
IPAQ incidental	25.1±13.6	23.19±18.3	0.77
IPAQ planned	6.7±4.6	2.9±2.1	0.01*
FES-I	9.9±2.6	10.5±2.7	0.55
WOMAC pain	171.7±241.2	249.8±339.1	0.54
WOMAC stiffness	46.8±50.4	61.5±30.6	0.38
WOMAC function	225.9±185.7	384.1±276.1	0.13

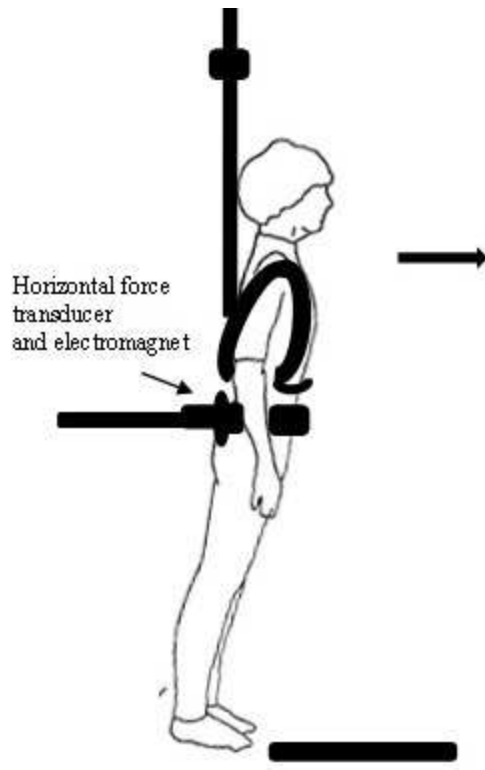
WOMAC total	444.4±402.0	695.57±579.7	0.25
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*Significant level $p < 0.05$; values are presented as mean \pm standard deviation.

†All knee strength measures are reported as %BW *Height and are for the responding leg during the balance recovery test.

Abbreviation: FSST- The Four Square Step Test ; postural sway M/L – medial lateral direction; A/P- anterior posterior direction; AQoL - Assessment of quality of life; IPAQ- Incidental and Planned Activity Questionnaire; FES-I – Short Falls Efficacy Scale International; WOMAC – Western Ontario and McMaster University Osteoarthritis Index; PPA - Physiological Profile Assessment.

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