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Effectiveness of multi-component balance specific training on active community-dwelling elderly

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Abstract

Introduction: Although impaired balance function is an important risk factor for unexpected falls in the elderly there is still no agreement regarding the type and intensity of training to decrease this impairment.

Purpose: The purpose of our study was to determine the efficacy of a specially developed multi-component balance-specific exercise programme with special emphasis on training on a compliant surface to improve the balance of active elderly living in an urban environment.

Methods: The training group consisted of 26 elderly, aged 69.6 ± 6.6 years. They participated in training twice a week for 12 weeks. A force platform was used to determine the movement of the body's centre of pressure during sensory organisation tests: quiet stance on a hard and compliant surface with eyes open and closed. To evaluate functional balance skills the four square step test and timed 10 m walk tests were assessed.

Results: After the training period the centre of pressure movement while standing on a hard surface did not differ significantly from pre-training. On the other hand, after training, standing on a compliant surface with open eyes was characterized by a significant decrease of both medio-lateral and antero-posterior sway as well as a decrease of the centre of pressure velocity and sway area. Closed eyes on a compliant surface resulted in smaller antero-posterior sway. The time needed to perform the four square balance test and timed 10 m walk test significantly decreased after the training indicating the transition of the acquired skills into the functional domain.

Conclusion: Multi-component balance-specific training on a compliant surface can improve balance of active, community-dwelling elderly. Even if it is performed only twice a week such training can, after three months, enhance postural stability, speed of stepping in different directions and gait speed.

Keywords: elderly, balance training, stabilometry, compliant surface, gait speed

Introduction

The population of EU member countries is projected for the period of 2008-2060 to become older where the median age of the total population is likely to increase in all countries without exception due to the combined effect of the existing structure of the population, persistently low fertility and a continuously increasing number of survivors to higher age [1]. In particular, the population aged over 65 years is expected to increase in all European countries, whereas Slovenia is predicted to be by the end of the third decade of this century already among the countries with the oldest population in the world with the increase of the population over 65 years from 16 % of the total population in 2008 to 25% in 2030 and 33 % in 2060 [1]. From the available data for Slovenia for the year 2009 [2] it is known that in the total population of 1000 persons 38 in the age group 60 to 74 years experienced accidental falls and were consequently hospitalized whereas this numbers were 107 in the age group over 85 years. It is also important to note that in 2009 over 60 % of total hospital treatments in Slovenia were caused by falls. The risk of accidental falls increases with ageing and the related reduction of physical ability. The prevalent consequences of accidental falls are hip and hand fractures, bruises, pains and as much as 4 % of the affected persons are reported to die as a consequence of a fall [3]. Falls in elderly quite often lead also to loss of independence, associated illness and diminished quality of life. They are not only harmful for the individuals but also present a great burden for the society as general. This data indicate that the problem of accidental falls in elderly is expected to become even direr and needs to be addressed as soon as possible.

Among the most important risk factors for falls is impaired balance [3]. Balance is closely related to muscular ability, range of motion especially of ankle joints, visual and other sensory inputs, as well as cognitive and emotional factors. Since human balance is a complex motor and cognitive function, a precise tuning between the proprioceptive, visual and vestibular systems together with the functional motor control system is necessary [4]. With ageing a decline is expected in motor functions such as muscle strength and endurance, in flexibility, in acuity and in the amount of sensory information from different sensory modalities including the somatosensory and vestibular systems [5]. It is expected that a deficit in any sensory system reflects a change of the processing of sensory information and the resulting motor response and thus also in balance and posture. Redundancy of the afferent inputs of the visual, vestibular and proprioceptive systems is therefore essential for optimal postural control. Visual and vestibular systems cannot completely replace the eventually missing somatosensory input while there exists some evidence that the appropriate somatosensory input can compensate for the missing visual and vestibular inputs [6]. During everyday activities it may happen that sensory information is conflicting and this may lead to loss of balance and even a fall. Such a case happens for instance when a subject is standing in a bus moving with constant speed - here the visual information is signalling movement whereas the vestibular and proprioceptive systems do not support it. The probability of falls in case of conflicting sensory information increases with the advancing age [7].

There is still no agreement between researchers about the type and intensity of training for the optimal enhancement or maintenance of balance function in elderly subjects. The only agreement appears to be on a minimum of 50 hours of training the dose necessary for inducing change in balance function [8]. General exercises may have beneficial effects on muscular strength and capacity but quite often their influence on balance function is minimal [9] or completely absent [10]. These results suggest that the improvement of muscle capacity is not directly transferred to balance function [11,12]. A balance-specific exercise programme is therefore an option to maintain or enhance balance in the elderly. It has been shown that balance-specific training with functional tasks that challenge balance is efficient in frail nursing home residents [13] as well as in functionally more able elderly [6].

Adding a sensory component to functional balance training, especially in the form of compliant or movable surfaces, presents an additional challenge for the postural control system. Namely, standing on a compliant surface alters two types of sensory inputs from the lower extremities. The information from the soles is modified by different pressure distribution under the sole and thus differently affects the cutaneous mechanoreceptors in the foot [14] which are essential for determining the position of the centre of pressure on the base of support. The other effect is dynamic - the elasticity of the supporting surface results in additional body movement which requires constant adjustments of the relative positions of body segments to keep the centre of gravity over the base of support [15]. Thus, for effective balance on a compliant surface not only are motor responses required but also attention to the performed task is required. Training on a compliant surface, which is occasionally also called proprioceptive training, is a type of senso-motor training. This training has been recently reported mainly in rehabilitation after muscular, knee ligament and ankle injuries [16]. It is reported that such training is effective in preventing repeated injury [17]. In the elderly the reported results of senso-motor training that includes training on compliant and moving surfaces are conflicting, some indicating that such sensory-specific training reduces the influence of mechanical destabilisation on body balance [18] and improves inter-muscular coordination [19], while others report no effect on postural sway [20].

In accordance with the system approach balance depends on the interaction between the individual, the task to be performed and the environment in which the task is carried out [21]. The components within the individual include the interaction of perception, cognition and motor systems. The motor system and its coordination further depends on accurate information from all sensory modalities. To address the complexity of balance a multi-component exercise programme is needed. This term denotes an intervention that incorporates multiple components, such as the activities targeting performance (muscle strength, endurance and/or power), balance, postural control and walking or cardiovascular endurance [8]. To date there is a limited amount of evidence on the efficacy of somatosensory-specific training, organised as group training, not on a one-to-one basis as, for instance, in the case of a therapist working with a patient. A protocol with predominant somato-sensory training was reported to improve the results of biomechanical and functional balance tests in elderly male subjects [19]. Besides, there even exists doubt as to the feasibility of a multi-component group training programme that would address motor and sensory components of balance in the same training session and would, additionally, incorporate range of motion and strength training [22]. It is still not clear whether balance-specific training that targets most of the sensory and motor systems could be effective for active elderly population. There was, thus, a twofold purpose to this work: first to evaluate the feasibility of a multi-component training programme organised as group training, and second to evaluate the efficacy of specially developed multi-component, balance-specific training programme, with emphasise on training on a compliant surface, to improve the balance function of active elderly living in an urban environment.

Methods

Participants

The participants were recruited by advertising in the publications of the Pensioners' Association of Slovenia and at the notice boards in senior clubs and day care centres. As a consequence 34 persons volunteered to participate in our balance-specific training programme, all of them community-dwelling in the region of the city of Ljubljana. Before enrolment in the training all participants were informed about the purpose and the programme of the training as well as about the procedures of data collection and they signed written consent. The study was approved by the National Medical Ethic Committee.

In the analysis only the results of those participants were included who regularly participated in the training programme (at least 75% adherence), whose score on the Berg balance scale [23,24,25] was over 46 points and who did not report any neurological problems. This reduced the number of subjects to 26; 21 women and 5 men. Characteristics of the study group are presented in Table 1.

Motor performances measures

To determine the levels of functional fitness and the level of balance prior to training programme functional tests were performed. The Berg balance scale consists of 14 functional activities graded on a scale from 0 to 4. It is valid [23], reliable [24] and sensitive to change [25]. Motor performances of lower extremities were tested by the timed stance on toes test [26] and hand grip strength was estimated using a hydraulic hand dynamometer Jamar (Lafayette Instruments, USA).

Outcome measures

Due to the complexity of balance a combination of tests were performed that measured various components of balance on the level of sensory systems (sensory organisation test) and on functional level (four square test and timed walking test). The main outcome measure of balance during quiet upright standing was tested with the sensory organization test on the force platform. It is a clinical tool for the assessment of the relative contribution of proprioceptive, vestibular and vision system to postural integration. The validity and reliability of the test is well-established [27]. Subjects were standing barefoot on the force

Table 1. Characteristics of the 26 participants of the balance-specific training programme.

	Average ± SD	Minimum	Maximum
Age (years)	69.6 ± 6.6	59	82
Body mass (kg)	71.3 ± 13.5	49	98
Height (cm)	160 ± 9.7	132	177

platform with their feet close together and arms at their sides in 4 different conditions: standing on a hard surface and on the Airex™ mat (40 x 48 x 6 cm) with their eyes open and closed.

Stabilometry was used to assess the amount of postural sway. Data were collected by a force platform (Kistler 9286 AA, Winthertur, Swiss) with a 50 Hz sampling rate using the BioWare program. Raw data were uploaded to a server with a Linux operating system and analysed by specially developed software [28]. The typical analysis of the stabilometric data started by data smoothing using Gaussian filtering of selected width (usually 2 or 3 data points). It then proceeded by plotting the time and frequency distributions, determining the outline of the measured data, calculating its Fourier coefficients and the total path length of the centre of pressure (CoP) movement as well as medio-lateral and antero-posterior total path lengths and finished by determining the sway area. More detailed description of the method is given in [29]. For the purpose of this analysis four sway parameters were chosen: mean velocity of the CoP during a 60 s measurement interval, medio-lateral and antero-posterior path lengths and the sway area.

Additionally, two functional and balance tests were performed. The four square step test [30], which is a reliable and valid clinical tool, was used to assess subjects' agility, weight transfer, and change of direction. This test has also a cognitive component as the subjects need to remember the sequences of the test, at the end of first cycle they need to change the direction and repeat stepping in a reversed order. Additionally, a timed 10 m walk test was performed that is a reliable measure of functional mobility [31].

Training protocol

The multi-component balance-specific training was designed in accordance with the system approach. This approach stresses the importance of the fact that any movement emerges from an interaction between the individual, the task and the environment in which the task is carried out [21].

The volunteers participated in the 60 minute multi-component balance-specific training sessions twice a week for 12 weeks. Each session consisted of two distinctive parts: the first one was devoted to warm-up, range of motion exercises and activation of all major muscular groups. The session started in standing position and proceeded lying sideways, supine and prone.

The second 30 minute part was designed as a circuit training at three different work stations. The aim of this part was to perform the tasks that progressively increased balance demands. This part consisted of training on a compliant surface, stepping on steps of different heights, walking around and over hard and soft obstacles, and performing various movements with upper and lower extremities while sitting on gymnastic balls. The compliant surface training workstation was aimed at preserving and stabilising balance in altered proprioceptive conditions. For these exercises 6 cm thick Airex™ mats of various dimensions and elasticity were used. The participants were standing on them with both feet parallel, toe to heel, or on one leg. All these activities were repeated with open and closed eyes. Besides, the participants were also walking forwards, sideways and backwards on a 2 m long and 20 cm wide compliant mat. Stepping on soft and compliant small stepping surfaces was also included. There were two assistants present at all times in case the participants required any assistance. The exercises were adjusted to the ability of the participants and if necessary they were performed in pairs or while touching a stable surface.

The second workstation was principally aimed at improving weight transfer and estimation of step height and included also a component of aerobic training. It consisted of activities on 18 cm high steppers, as used for aerobics, that correspond to standard step height. The participants were stepping on steppers forward, sideways or over them. During the training the frequency and the repetition counts were adjusted to the individual abilities.

The third workstation consisted either of a polygon with obstacles or training sitting on big gymnastic balls. The polygon included walking on a compliant surface, stepping over obstacles of different heights, walking around objects of various sizes, 360 degree turning, walking while carrying objects and sitting on surfaces of different heights. This group of exercises emphasised not only stepping on a compliant surface but also the ability of changing the base of support and approaching its limits, vestibulo-ocular stabilisation, changing the direction of movement and double attention. The exercises performed while sitting on a big gymnastic ball presented a moving base of support and constant changes of its size and the number of available fixed points. This group of exercises enabled the training of proactive balance where the activities demanded anticipatory postural adjustments and of the reactive balance with the demands for reacting to the moving base of support.

Statistical analysis

The Statistical Package for Social Sciences (SPSS 17, SPSS Inc., Chicago, IL USA) and Microsoft Excel 2003 (Microsoft Inc, Redmond; WA, ZDA) was used for statistical analysis. A paired t-test was performed to identify the difference between pre- and post-training outcome measures. The significance level was set at $p < 0.008$ after a Bonferroni correction was applied.

Results

Pre-training motor performances

Before training the functional level of balance was determined, as well as the hand grip strength and the strength of triceps sure muscle of lower extremities. The results (Table 2) show high functional level for the age group [32]. Thus, most of the subjects were graded with over 49 points at Berg balance scale and the time of the stance on toes test was 54.6 ± 11.6 seconds. The results for the hand grip strength (Table 2) are given separately for males and females and left and right hands. In all cases the dominant hand was the right one.

Stabilometry

Postural steadiness was defined as the movement of the body centre of pressure (CoP) on the force platform (postural sway) in a given time interval. The results in Table 3 show that three months of balance-specific training did not affect postural sway while standing on a solid surfa-

Table 2. Pre-training Berg balance scale and muscle strength for hand and foot.

	Average ± SD	Minimum	Maximum
Berg balance scale (scale)	54 ± 2	49	56
Stance on toes (s)	54.6 ± 11.6	20.1	60
Hand grip strength – female left hand (kg)	24.9 ± 5.5	12	34
right hand (kg)	28.2 ± 6.4	18	42
Hand grip strength – male left hand (kg)	48.3 ± 12.1	39	62
right hand (kg)	46.3 ± 7.8	40	55

*Table 3. Centre of pressure movements during four conditions of sensory organisation test before and after training. (The significantly different results are bolded. The level of significance is indicated as: ** p < 0.01, *** p < 0.001)*

	Solid surface, eyes open	Solid surface, eyes closed	Compliant surface, eyes open	Compliant surface, eyes closed
Medio-lateral path (cm)			***	
pre-training	58.4 ± 21.4	96.6 ± 36.4	132.3 ± 35.2	293.7 ± 79.8
post-training	57.9 ±17.2	100 ± 53.4	110.1 ± 30	272.8 ± 87.3
Antero-posterior path (cm)				**
pre-training	46.5 ± 19.6	75.6 ± 40	104.5 ± 24	274.7 ± 84.6
post-training	43.2 ± 15.1	75.5 ± 44	98.2 ± 33.5	236 ± 79.9
Mean velocity (cm/s)			**	
pre-training	1.4 ± 0.5	2.3 ± 0.9	3.1 ± 0.7	7.5 ± 2.1
post-training	1.3 ± 0.4	2.3 ± 1.2	2.7 ± 0.8	6.9 ± 2.1
Sway area (cm^2)			***	
pre-training	4.7 ± 2.8	8.7 ± 7.2	14. 6 ± 4.3	55. 6 ± 29.2
post-training	4.2 ± 1.6	7.9 ± 5.4	11.1 ± 3.8	41 ± 17.9

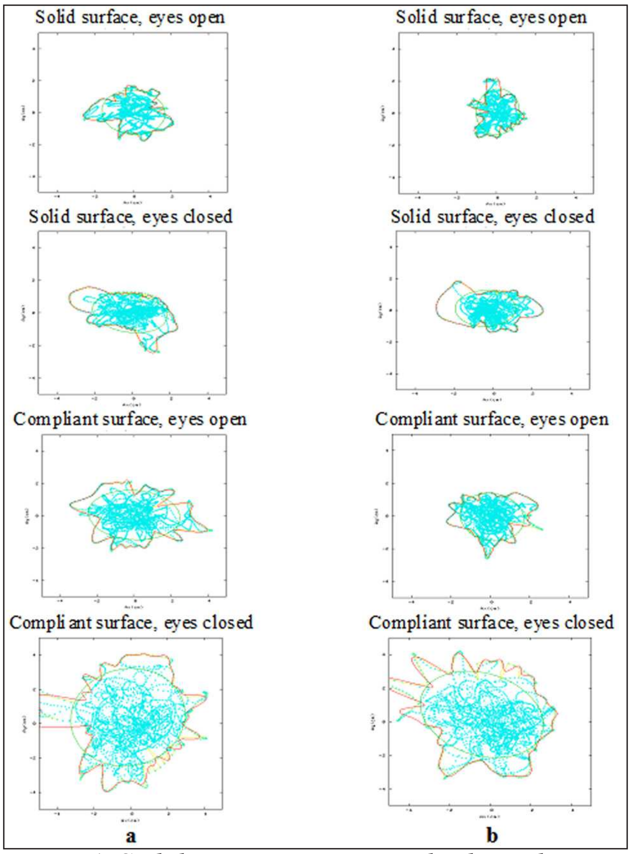

Figure 1. Stabilograms in one typical subject during the sensory organisation test on the force platform performed on a solid and compliant surface with eyes open and closed before training (a) and after three-months of balance-specific training (b).

ce, regardless of whether the eyes were open or closed. The training resulted in reduced postural sway on a compliant surface with eyes open. Specifically, statistically significant differences were observed for the reduction of medio-lateral path ($t = 3.92$, $p < 0.001$) and mean velocities ($t = 2.85$, $p = 0.009$). Similarly, the surface areas of the centre of pressure paths were also smaller after training ($t = 3.53$, $p = 0.002$). The postural sway on a compliant surface with eyes closed was also reduced by training. The post-training antero-posterior centre of pressure paths were significantly shorter ($t = 2.79$, $p = 0.014$) and the sway areas were smaller ($t = 2.36$, $p = 0.03$). Some typical examples of the centre of pressure measurements are shown in Figure 1 for four conditions of sensory organisation tests before and after training.

Functional and balance tests

The time needed to complete the four square step test after the training was significantly less ($p = 0.003$) compared to pre-training values (9.7 ± 2.1 and 8.6 ± 1.5 seconds respectively, Figure 2). Walking speed also significantly improved after the training period, subjects needed significantly less time for the timed 10 m walk test $p < 0.001$, (7.6 ±1.1 and 5.2 ± 0.5 respectively, Figure 2).

Discussion

The results of this study show that multi-component, balance-specific training with an emphasis on training on a compliant surface, as described above, can improve the balance of community-dwelling elderly that are still independent at daily activities and are even recreationally active. Training induced change was observed as enhanced steadiness on compliant surface as well as improved functional balance and walking tests.

The participants were elderly that have, on the basis of responding to advertisements, shown an interest in this type of training. They were relatively physically fit for their age group (Table 2) and without any serious health problems. It was thus reasonable to expect that in a three-month time period their motor and balance functional parameters would not significantly change, especially not improve, were they not engaged in any specific training. Taking this into consideration we decided against a control group. This was also supported by ethical considerations where as little as possible additional stress is to be put on the population by the research, where testing would occur without intervention. Our choice was further justified by the post-training stabilometric results where the postural sway on solid surface

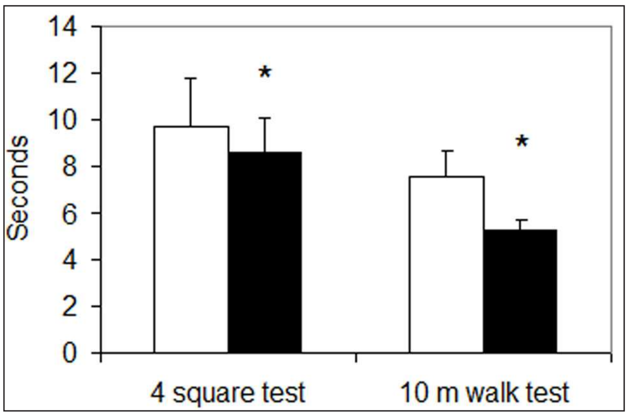

Figure 2. Pre (white) and post (black) training values for four square balance test and timed 10 m walk test significantly decreased after the training period.

with eyes open or closed remained the same after three-months training period. It is thus reasonable to attribute all eventual post-training differences to the direct or indirect impact of the balance-specific training, though possible placebo effects are recognised.

The participants of our training programme had well preserved balance function which is indicated by high scores of Berg balance scale as reported in Table 2. Besides, the results of the timed stance on toes and of hand grip strength tests are on the upper part of those expected for the appropriate age group [33].This data exhibits that subjects were fit and despite this fact were able to improve balance on compliant surfaces as well as in the 4 square and walking speed tests. This implies that low intensity but functionally specific training is capable of inducing change even when subjects are fit and highly functioning.

The sensory organization test on the force platform showed improved stabilization of the centre of pressure on a compliant surface after training whereas there were no significant changes for standing on a hard surface with eyes open or closed. These results suggest that the participants learned during the training to rely more on the visual and vestibular inputs and thus compensate for the change imposed by the compliant surface on the information coming from the somato-sensory system. It is unlikely that the somato-sensory system (as represented by conduction velocity, number of receptors present, etc) was influenced by the exercises, the change was more likely on the level of central processing of these stimuli. This is proposed due to the limited plasticity of the somatory system. The increased ability of stabilisation of the COP as a result of the described training protocol could be explained by the theory of sensory re-weighting [34], which suggests that the central nervous system can dynamically adjust the relative weights of the incoming sensory data and thus optimize the balance control. It seems that after the balance-specific training the participants were able to more effectively use the inputs of their muscular and ligament stretch receptors which are particularly active during constant body adjustments when standing on a compliant surface [15].

The ability of weighting and re-weighting of the incoming sensory inputs remains present in the elderly as does the ability for adjustments of the neuromuscular and musculoskeletal systems [35,36]. Regular physical activity, even if started later in life, can result in reorganization of postural control components and improve balance under conflicting sensory information [35]. When properly stimulated, the adaptability of systems involved in the control and performance of motor function is known to be preserved also in very old subjects. This applies to the acquisition of muscle force and capacity [36], as well as to the complex function of balance [13]. Besides, moderate physical activity is also beneficial for diminishing oxidative stress and reducing the inflammatory process in the elderly [37].

Besides better stabilisation on compliant surfaces, improvement in functional balance was observed. Changes were observed in the four square step test and 10 m walk test. In both tests subjects performed faster after training indicating the increased balance skills that consequently allowed subjects to walk faster. Subjects were also able to stand significantly longer on a narrow supporting surface with their eyes closed. Previous results showed improvement in gait speed and balance tests as a result of balance-specific training in subjects with reduced balance [38] and nursing home residents [13]. These results support the functionally-oriented, multi-component group training protocol that has the potential to be transferred to different environments as well as to everyday life, which should be goal of any motor learning process [39]. In contrast, traditional group training, consisting of exercises that activate the whole body and include stretching and relaxation, is not reported to be of great value for balance improvement [11,12].

Doubts have been proposed as to the feasibility and capability for eliciting change in balance and functional performance when training consists of strength, aerobic and balance training in the same session [22]. In the present study range of motion, strength maintenance and balance-specific training was administered in the same session, with positive results. Similar studies exist in the literature with the major difference between the present work and these studies being the multi-component nature of the present work that included training on compliant surfaces. Frye et al. [40] reported an increased speed in the up and go test in the group who performed low intensity exercises with main elements of strength, flexibility, endurance and balance as compared to a control group. Iwamoto [41] programme consisted of callistenics, body balance training, muscle power training, and walking and reported an increase of tandem and one leg standing time and increased gait velocity in the exercise group as compared to controls. The programme also decreased the incidence of falls in the exercise group. It may be concluded that multi-component, balance-specific training that includes senso-motor training (standing on compliant surfaces) is effective for a predominantly female group (present study). Others have found training on a compliant surface to be effective in active, community-dwelling males [19]. However, it is still not possible to conclude that balance-specific training, with an emphasis on somato-sensory training, is more effective than other types of training as the research results are often conflicting. Some could find no difference between functional training and resistance exercise training [42] and no difference could be determined between functional and traditional training [38]. Only a systematic study of different training protocols in groups of elderly of various, but matched, balance performance skills can resolve this question.

Conclusion

A multi-component, balance-specific training which emphasised standing on a compliant surface improves balance during postural stabilisation tests and is transferred to other functional activities. These results show that even active elderly persons can improve their balance function provided it is reasonably well-preserved at the initiation of training. We can also conclude that multi-component, balance-specific training can be organised ingroup training and that combining different types of exercises is feasible and effective. The effectiveness of this training needs to be compared with other training protocols.

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