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DO FUNCTIONALLY FIT ELDERLY COMMUNITY-DWELLING SUBJECTS HAVE ENOUGH TIME TO SAFELY CROSS THE ROAD?

ABSTRACT

Elderly people are the most vulnerable group in urban traffic and a large proportion of them are as pedestrians victims of traffic accidents. The majority of these happen while crossing the road. Crossing a busy road at an intersection with traffic lights or without them is a typical dual task condition requiring a motor task i.e. walking and a cognitive task such as monitoring traffic. The purpose of present study was to compare the walking speed and the related spatio-temporal gait variables of fallers and non-fallers in three walking conditions against the speeds required by regulations in Slovenia for safe street crossing. To assess the spatio-temporal characteristics of gait we used a 7m instrumented walkway.

The general results showed that the spatio-temporal gait parameters did not differ between the two groups at the self-selected speed. But as soon as a constraint, such as fast walking speed, was imposed on the subjects the differences between the groups became evident. Fallers demonstrated a significantly slower mean gait velocity and shorter stride length while the cadence and the base of support did not differ between the two groups. In dual task conditions the difference between the two groups reached 25 percent. The fallers group gait velocity dropped to 0.99 m/s. The observed walking speed was slower than considered by the guidelines for the design of traffic light equipped road crossing.

In conclusion, the results of walking speed under dual task conditions could be a useful parameter for planning of optimal pedestrian crossing in urban areas. These results will serve for the design of a population based study in Ljubljana.

KEY WORDS

elderly, walking speed, dual tasking, street crossing

1. INTRODUCTION

The number of elderly persons in urban areas in the European Union has been gradually increasing. The population aged over 65 years is expected to increase in all the European countries from 17% of the total population in 2008 to 24% in 2030 and 30% in 2060 [1]. Therefore, with the rising population of the elderly the number of elderly subjects engaged as pedestrians in traffic will be increasing, too. The international accident statistics indicates that elderly pedestrians are an extremely vulnerable road user group [2]. Elderly persons are considered a “Vulnerable road user”, a term which applies to those most at risk in traffic, and are reported to account for half of the fatalities on the world roads [3]. In Slovenia, between 40 and 50 percent of elderly subjects involved in traffic accidents are pedestrians [4]. The analysis of the elderly pedestrian accidents [5] revealed that most accidents were due to falls at the time of road traversing and/or failing to estimate the distance of an approaching vehicle. The types of injuries sustained by the victims were craniocerebral (48%), followed by the lower limb (46%) and upper limb injuries (31%). The consequences of a fall are detrimental for the individual and are a large burden for the public health care system. In Slovenia for instance, 60 percent of hospitalisations due to trauma in the year 2009 were those which resulted as a consequence of falls [6].

The phenomenon of accidental falls has been associated with multiple causes ranging from attention problems to physical weaknesses. Generally, falls among elderly community-dwelling subjects most often occur while walking on level or uneven surfaces [7]. The majority of the falls occur during dual tasking while walking or during other upright activities [8]. The other major reason for falls in the elderly is tripping during walking and this has been reported to account for 53% [9] to 59% [7] of falls. Trips that occur during walking are often triggered when the recovery foot strikes an obstacle in its path during the swing phase of gait. Hazardous obstacles are found both in and outdoors and vary in height from a few millimetres, in the case of a crack in the pavement, to more than 15cm for a kerb [7].

When crossing a zebra crossing equipped with traffic lights many older pedestrians report inability to complete the crossing in the time given by pedestrian lights [10]. The methodology to calculate the time needed by pedestrians to cross the road equipped with traffic lights in the city of Ljubljana, Slovenia, are specified in guidelines [11]. According to them the pedestrian clearance time of road crossings depends on the walking speed, the crossing width and the number of pedestrians per area. As compared to laboratory gait measurements, crossing real roads requires a great deal of attention and multi sensory integration. Largely increased input from vision and hearing is expected from traffic where elderly persons are engaged as pedestrians. Typically, a pedestrian would need to negotiate obstacles such as uneven pavement curbs and consider other pedestrians on a sidewalk. When crossing a road, the pedestrians have not only to walk but also to monitor traffic, determine whether there is enough time to cross, and to adapt their action to the continuous perception of oncoming vehicles. The underlying skill involves being able to calibrate perception and action, and requires typically multiple tasking or dual attention [12].

To evaluate the impact of cognitive tasks on gait the paradigm of dual task has been used [13]. Impaired dual tasking and accidental falls have received considerable attention; however, the results are heterogeneous, some report that impaired dual tasking is associated with falls [14, 15, 16] while others have found that it is not associated with falling at all [17, 18] or is an irrelevant indicator compared to impaired single task performance [19, 20]. Crossing a busy road at an intersection with traffic lights or without them is a typical dual task condition requiring a motor task, i.e. walking and a cognitive task such as observing traffic and decision-making for timing of the crossing. Therefore, we decided to evaluate the influence of dual tasking upon the walking speed in a group of fit community-dwelling elderly subjects under three different conditions: self-selected walking speed, fast though safe walking speed, and walking while naming animals. We hypothesised that in more demanding conditions the subjects who experienced a fall in the last year might show a decrease in performance that could influence their safety as pedestrians. The purpose of present study was thus to compare the walking speed and the related spatio-temporal gait variables of fallers and non-fallers in three walking conditions against the speeds required by regulations in Slovenia for safe street crossing.

2. METHODS

Twenty-three elderly persons aged 69.3 + 6.9 years, community-dwelling subjects volunteered for this study. All were participants in the balance-specific training programme based on the functional activities where typically balance is challenged as described in [21]. The study was approved by the Medical Ethic Committee of Slovenia and all subjects gave their informed consent prior to testing. Subjects were divided into two groups; the first one consisted of 17 subjects who did not experience any fall in the past year and the other 6 subjects who did. By five subjects the falls happened outdoors (on a street or a path), and one fall happened indoors. As a consequence two subjects received medical assistance. No fall resulted in a fracture or hospitalisation. The age, body weight and height did not differ between the two groups (p ranging from p = 0.499 to p = 0.973).

The balance function of all subjects was assessed by Berg balance scale (BBS) [22], timed tandem stance with eyes open and closed, timed stance on the toes [23]. The BBS consists of 14 functional activities graded on a scale from 0 to 4. It is valid and reliable [24]. The timed tandem stance is a clinical tool for assessment of the relative contribution of proprioceptive, vestibular and visual systems to postural integration. The results of balance tests for both groups together with descriptive statistics are given in *Table 1*. Balance tests BBS, timed tandem stance with eyes

Table 1 - Descriptives and level of balance as measured with Berg balance scale, tandem stance and muscle strength foot, average for all 23 participants and of the two sub groups - fallers and non-fallers

	Average ± SD (N = 23)	Non-fallers ± SD (N = 17)	Fallers ± SD (n = 6)	p
Age (years)	70 ± 7	69.4 ± 7.1	71.8 ±8.4	0.499
Body mass (kg)	69 ± 14	68.7 ± 13.5	69 ± 17	0.973
Body height (cm)	162 ± 6	161.7 ± 5.9	162 ± 8.1	0.934
Berg balance scale (pts.)	55 ± 1	55 ± 1	54 ± 2	0.192
Timed tandem stance with their eyes open (s)	59 ± 4	58	60	0.536
Timed tandem stance with their eyes closed (s)	55 ± 15	52	60	0.386
Timed stance on the toes (s)	49 ± 18	54 ± 11	32	0.027

open and closed did not differ between the two groups ($p = 0.192$, $p = 0.536$, $p = 0.386$, respectively). The timed stance on the toes however, differed between the two groups, the non-faller group stood on toes on the average for 54 ± 11 seconds and the fallers group for 32 seconds ($p = 0.027$).

2.1 Instrumentation

To assess the spatio-temporal characteristics of gait we used a 7m long GAITRite® instrumented walkway (Havertown, USA). The sampling rate of data acquisition was set to 100Hz. The data were uploaded into a computer using Gaitrite 3.3 software. Testing was performed in a wide and quiet walkway with no auditory or visual interferences where the participants walked with their own footwear. The subjects walked in three sequencing conditions: normal walking with self-selected speed, fast walking speed and walking with a simultaneous cognitive task. The verbal fluency task was used as the cognitive task. Verbal fluency is the ability to produce novel and context-appropriate response to a given topic. The subjects were instructed to say aloud as many animals as possible. In order to create real life conditions when dual tasking, the subjects were instructed to give equal priority to both tasks.

The standardised instructions were in accordance to the guidelines for clinical applications of spatio-temporal gait analysis in older adults [25]: usual walking speed as if going shopping, as fast as possible as if hurrying for the bus, usual walking and at the same time naming as many animals as possible. To acquire sufficient data points for further analysis the subjects were asked to walk three consecutive walks at a given experimental condition. They walked along a 30m long ellipse, where one of its longitudinal consisted of a 7m GAITRite® walkway. Each walk series was initiated over at least 2m walkway before the measuring carpet to allow for sufficient distance to accelerate from a steady state of ambulation across the walkway. Before data collection the subjects practised walking over the walkway in order to familiarize themselves with the test procedure.

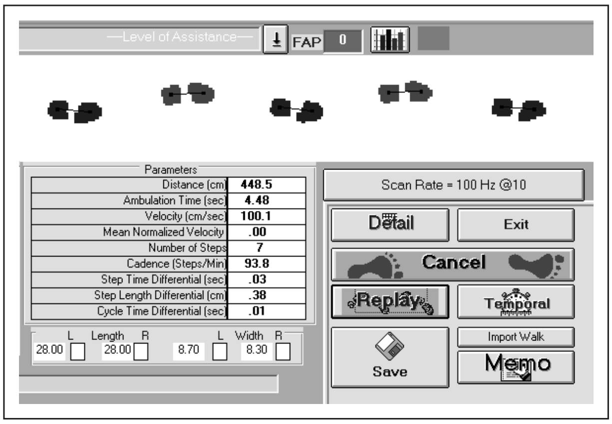

Figure 1 - An example of the reading from Gaitrite® walkway that allowed calculations of stride length which is measured between the heel points of two consecutive footprints of the same foot (left to left). The base of support width is the vertical distance from the heel centre of one footprint to the line of progression formed by two footprints of the opposite foot[1]

The four spatial and temporal gait measures (parameters) were evaluated: walking speed (cm/s), stride length (cm), cadence (steps per minute) as well as the width of the base of support (cm) which is the vertical distance from the heel centre of one footprint to the line of progression formed by two footprints of the opposite foot[1]. Because data from the left and right strides did not differ, only data from left side were analysed.

2.2 Statistical analysis

The Statistical Package for Social Sciences (SPSS 17, SPSS Inc., Chicago, IL USA) was used for statistical analysis. A two-way analysis of variance (ANOVA) was performed to identify the effect of gait type (self-selected speed, fast walking speed and dual tasking), and accidental fall (subjects who experienced fall and those who did not) on each of the dependent measures and to identify the interaction between the two groups of subjects. The significance level was set at $p < 0.05$.

3. RESULTS

The mean values with standard deviations of all gait parameters in the three types of walking conditions for the non-fallers and fallers subgroups is given in *Table 1*.

A 3 (type of gait) x 2 (group: non-fallers and fallers) between subjects ANOVA was calculated comparing the gait velocity for elderly community-dwelling subjects who had walked in three conditions and had or had not experienced a fall in the past years' time. A significant main effect for the type of gait was found ($F(2, 63) = 29.114$, $p < 0.001$). Both groups walked more slowly when dual-tasking as compared to normal walking speed and fast walking. A significant main effect for the group, whether subjects experienced fall or not (non-fallers and fallers) was found ($F(1, 63) = 13.127$, $p = 0.001$). Subjects who did not experience a fall had significantly higher average velocity than fallers in fast walking ($p = 0.038$) and when dual-tasking ($p = 0.034$). The interaction was not significant ($F(2, 63) = 0.443$, $p = 0.644$), the effect of velocity between the type of gait was not influenced by whether or not the subjects experienced falls or not.

A 3 x 2 between subjects ANOVA was calculated for the stride length. A significant main effect for the type of gait was found ($F (2, 63) = 7.836$, $p = 0.001$). Both groups had shorter stride length when dual-tasking as compared to normal walking speed and fast walking (*Table 1*). The main effect for group was significant ($F (1, 63) = 15.876$, $p < 0.001$). There was a difference in stride length - subjects who did not experience a fall had significantly longer stride lengths than fallers while fast walking ($p = 0.020$) and when dual-tasking ($p = 0.028$). The interaction was not significant ($F (2, 63) = 0.246$, $p = 0.782$). The stride length between the type of gait was not influenced by whether or not the subjects experienced a fall or not.

A 3 x 2 between subjects ANOVA was calculated for cadence. A significant main effect for the type of gait was found ($F (2, 63) = 37.29$, $p < 0.001$). The cadence in the dual-task condition was lowest (*Table 1*) for both groups of subjects. The main effect for group, whether subjects experienced fall or not, was not significant ($F (1, 63) = 1.546$, $p = 0.218$). There was no difference in cadence between subjects who did not experience fall as compared to those who did (*Table 1*). The interaction was not significant ($F (2, 63) = 0.824$, $p = 0.444$). The cadence at all types of gait was not influenced by whether or not the subjects experienced a fall.

A 3 x 2 between subjects ANOVA was calculated for the base of support. The main effect for type of gait was not significant ($F (2, 63) = 0.028$, $p = 0.972$). The main effect for group was not significant ($F (1, 63) = 0.127$, $p = 0.723$). Finally, the interaction was also not significant ($F (2, 63) = 0.322$, $p = 0.726$). These results indicate that base of support is not influenced either by gait velocity or by the experience of falls.

Relative difference of gait speed was calculated as a function of gait type. When subjects walked at self-selected speed the ones with the experience of falls walked on average 11 percent slower as compared to non-fallers, the difference was not statistically significant ($p = 0.089$). But while walking fast the fallers walked 18 percent more slowly than non-fallers and this difference was statistically significant ($p = 0.038$). When walking in dual task conditions fallers walked 25 percent more slowly as compared to non-fallers and the difference was statistically significant ($p = 0.034$). These results indicate that subjects who had experienced a fall demonstrate a decrease in walking speed as motor and cognitive demands increase.

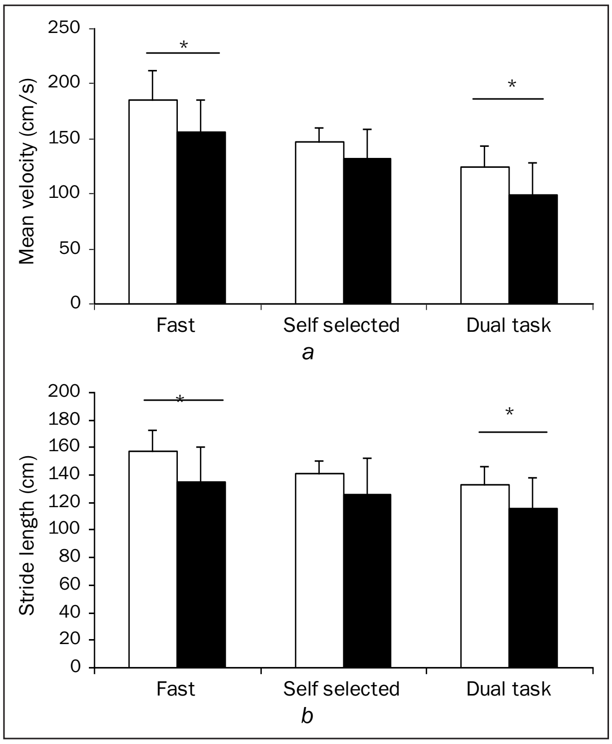

*Figure 2 - Mean velocity (a) stride length (b) for three walking speeds: fast walking, self-selected walking speed and in dual-task conditions for non-fallers (white) and fallers (black). Significant difference (p < 0.05) between the groups is labelled**

Table 1 - Average values and standard deviations for gait variables as measured at three types of gait for both groups: those who did not experience a fall and those who did. The significant differences between the fallers and non-fallers are bolded.

	Self-selected speed	Fast walking	Dual-tasking
Average speed (cm/s)			
Non-fallers	147 ± 13	185 + ± 27	124 ± 20
Fallers	132 ± 27	**156 ± 29**	**99 ± 29**
Cadence (steps/min.)			
Non-fallers	125 ± 8	141 ± 13	111 ± 12
Fallers	125 ± 3	140 ± 7	101 ±19
Stride length (cm)			
Non-fallers	141 ± 9	157 ± 16	133 ± 13
Fallers	126 ± 26	**135 ± 25**	**116 ± 22**
Base of support (cm)			
Non-fallers	7.6 ± 2.3	7.7 ± 2.5	7.3 ± 2.5
Fallers	7.5 ±+ 2.9	7.6 ± 2.2	8.3 ± 2.6

4. CONCLUSION

The purpose of the present study was to evaluate the fall-related differences in gait speed and related gait parameters in three walking conditions: self-selected speed, fast walking and in dual-task conditions of elderly community-dwelling subjects. The participants were divided into a group of fallers, the subjects who experienced an accidental fall in the past years' time, and a group of non-fallers. The general results showed that the spatio-temporal gait parameters did not differ between the two groups while walking at self-selected speed. As soon as a constraint such as fast walking speed was imposed on the subjects, the differences between the two groups became evident. Fallers demonstrated a significantly slower mean gait speed and shorter stride length, while the cadence and base of support did not differ between the two groups.

As indicated in *Table 1* this group of elderly community-dwelling subjects had high scores in balance tests. Both groups reached 55 or 54 points respectively, out of 56 maximal score, a score of less than 46 points was reported to indicate subjects that are prone to falling due to insufficient balance [26]. These data indicate that participants of our study were fit and physically active but still there were about a quarter (26%) of them who experienced accidental falls in the past year.

When self-selected speed was evaluated the results showed that walking speed of the two groups was similar and ranged between 1.3 to 1.4 m/s. This result is in line with what could be expected for this age group [27] and had been previously reported by [28]. The related stride length and cadence did not differ between the two groups. The same applied for the stride width. It indicates that fall history does not affect walking speed when subjects choose it by themselves.

When instructed to walk as fast as if they were in a hurry, the subjects in the fallers group walked significantly slower as compared to non-fallers who developed a speed of 1.9 m/s and fallers were 18% slower with 1.6 m/s. Both walking speeds are within the range that is advised for calculating the minimal clearance time [11]. This agrees with the guidelines for the traffic light crossings in Ljubljana urban area [11]. Although fallers were still able to increase their walking speed our results indicate that subjects with an experience of a fall are not able to or hesitate to develop gait speed as fast as non-fallers. In traffic situations of crossing the road in particular, often maximal though safe walking speed is required.

When dual-tasking the subjects with fall experience walked significantly slower as compared to non-fallers. Their walking speed dropped to 0.99 m/s. The fallers were 25% slower compared to those subjects who did not experience an accidental fall. Besides the gait speed the secondary cognitive task influenced the stride length which was in both groups shorter in dual-task conditions as compared to walking alone. This speed dropped below the lowest value of walking speed that is used for the calculation of the clearance time of road crossings in Ljubljana. The guidelines [11] require the slowest walking speed of 1.2 m/s and the fastest of 1.5 m/s. The slowest walking speed is used when calculating the clearance time in the shopping areas, around schools and areas where there are more elderly pedestrians. More elderly-friendly are the guidelines of Transportation Research Board of National Research Council [29] that suggest to use the walking speed of 1.0 m/s in areas where more than 20 percent of persons older than 65 use road crossings. In Dublin for instance [10] a standard single carriageway (18.3 m) requires only 0.86 m/s speed to be successfully crossed.

The results of dual-task conditions indicate that both groups decreased their walking speed which is in agreement with previous results [30]. But it became apparent that in a more challenging condition, such as dual-task conditions, the difference between the two groups increased and reached 25 percent. Here, the fallers' group gait velocity significantly decreased and dropped to the level that was below the expected walking speed for safe road crossing [11]. Besides additional cognitive load additional motor task has also been found to cause reduction of walking speed in fallers [28]. It is expected that with the increasing age the influence of various cognitive tasks on posture and gait will increase [31].

Our results are in agreement with those of previous studies where the influence of fear of falling on spatial and temporal gait parameters was assessed. In [32] it is reported that a fearful group of elderly community-dwelling subjects had significantly slower gait speed and shorter stride length as compared to a fearless group. Beside these two variables also stride width was longer [32], on the contrary, our participants who experienced a fall did not display wider base of support.

A large population-based study [33] demonstrated that subjects who had difficulties in crossing a street reported in 81% of cases insufficient available time to cross. Normal walking speed of at least 1.22 m/s is required to complete the crossing task [27]. Construction of refuge islands for pedestrians is of interest to protect the pedestrians from collision with motor vehicles [34, 11] allowing slow pedestrians to safely cross the road. The research in the field of gait speed indicates that the timing of green light at pedestrian cross walks might be too short even for fit elderly community-dwelling subjects and might need readjustment to improve pedestrian safety for the elderly. For safe road crossing not only the speed to travel the distance is required but also a decision when, if at all, to cross the road, the reaction time and preparation time should be taken into account when calculating the time for street clearance by elderly pedestrians in an urban environment [35].

The results of our study together with the previous related studies can add to the body of knowledge and to the decision-making process when evaluating and designing safe pedestrian crossings. For instance [36] defined the criteria for the selection of optimal pedestrian crossing. The traffic intensity and the length of the pedestrian crossing were two important safety criteria for the selection of the optimal pedestrian crossing. When analysing the safety of a pedestrian crossing in addition to this criteria the number of elderly persons in the community where the pedestrian crossing is located should be taken into consideration.

Our research was not aimed at accurately representing the independent community-dwelling population at large as it used a volunteer sample. This must be taken into account when comparing the results of the present study with the ones that use representative samples. Besides, due to small sample size our results lack generalizability and must be considered as preliminary results. Anyhow, our results show that even highly capable (with high functional capacities) elderly subjects decrease their gait speed in dual-task conditions even in a safe and quiet environment of a gait laboratory. Since laboratory settings are known to influence a person's response and influence gait speed even slower gait is expected in real environment. Namely, slower crossing times were found in an outdoor simulated street crossing as compared to an indoor crossing [37].

As this study was carried out in an active, healthy population, it could be speculated that the deterioration of dual-tasking performance would be even worse in subjects older than the present study sample since the dual tasking capacity is age-dependent [31]. The results of our study will serve to prepare a population-based study in the city of Ljubljana, Slovenia, which could improve road safety in regions with ageing population.

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POVZETEK

ALI LAHKO SAMOSTOJNI, V DOMAČEM OKOLJU ŽIVEČI, STAREJŠI VARNO IN DOVOLJ HITRO PREČKAJO CESTO?

Starostniki so najbolj ranljiva skupina v mestnem prometu, saj predstavljajo velik delež med udeleženci prometnih nesreč. Večina teh se zgodi med prečkanjem ceste kar je tipičen primer dvojne naloge kjer oseba poleg gibalne naloge (hoja) opravlja tudi kognitivno nalogo kot je na primer opazovanje prometa. Namen pričujoče študije je bil primerjati hitrosti hoje, in z njo povezanih prostorsko-časovnih parametrov, oseb, ki so v času enega leta padli in tistih, ki se jim to ni zgodilo, v treh različnih pogojih (normalna in hitra hoja ter dvojna naloga), ter te rezultate primerjati s priporočili za izgradnjo cest v mestu Ljubljana. Parametre hoje smo izmerili s pomočjo elektronske sedem metrske merilne preproge.

Rezultati so pokazali, da se prostorsko-časovni parametri hoje med obema skupinama niso razlikovali kadar so osebe lahko same izbrale hitrost hoje. Kakor hitro pa se je pojavila dodatna zahteva, kot na primer zahteva po zelo hitri hoji, pa se je nastala razlika med obema skupinama. Osebe, ki so padle so v povprečju hodile počasneje in s krajšimi koraki, kakor tiste, ki niso padle vendar pa se širina podporne ploskve med skupinama ni razlikovala. V primeru dvojne naloge sta se skupini med seboj razlikovali celo za 25%, pri čemer se je hitrost hoje oseb z izkušnjo padca zmanjšala celo na 0,99 m/s. Izmerjena povprečna hitrost hoje je bila tako nižja od hitrosti, ki jo navajajo priporočila za načrtovanje semaforiziranih prehodov za pešce.

Iz te raziskave zaključimo, da so lahko rezultati meritev parametrov hoje v primeru dvojne naloge pomemben parameter za načrtovanje prehodov za pešce v mestnem okolju. Naši rezultati bodo uporabni za načrtovanje populacijske študije v Ljubljani.

KLJUČNE BESEDE

starostniki, hitrost hoje, dvojna naloga, prehod za pešce

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