ORIGINAL ARTICLE

The Segway Personal Transporter as an Alternative Mobility Device for People With Disabilities: A Pilot Study

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ABSTRACT. Sawatzky B, Denison I, Langrish S, Richardson S, Hiller K, Slobogean B. The Segway Personal Transporter as an alternative mobility device for people with disabilities: a pilot study. Arch Phys Med Rehabil 2007;88:1423-8.

Objectives: To determine the functional measures that best correlate with the skill levels of people with disabilities who operate a Segway Personal Transporter, and—using a qualitative analysis—to explore subjects' experience with the Segway.

Design: A prospective study encompassing 3 training sessions with the Segway to correlate subjects' functional ability (eg, cognition, balance, mobility, muscle strength) with their skill level on the device.

Setting: A provincial adult rehabilitation center.

Participants: Twenty-three subjects (age range, 19–65y) with a wide range of disabilities (eg, multiple sclerosis, spinal cord injury, amputation) who could walk at least 6m with or without assistance.

Interventions: Not applicable.

Main Outcome Measures: Segway Task Assessment, Berg Balance Scale, and Timed Up & Go test.

Results: No correlation was found because all participants successfully completed the final Segway Task Assessment, regardless of scores on functional assessments.

Conclusions: The Segway is a useful device for a broad range of populations with functional disabilities. Subjects found the Segway easy to use and were excited about its potential as an assistive device for use in their communities.

Key Words: Assistive technology; Disabled persons; Rehabilitation; Residential mobility.

THE SEGWAY PERSONAL Transporter,[a] introduced in 2001, is described as "the first self-balancing, electric-powered transportation device."[1] A rider stands on a small platform supported 20cm off the ground by 2 parallel wheels, and holds onto handlebars. A twist grip on the left bar is used to steer the device. When the rider leans forward, the Segway moves forward and when the rider leans back, it moves back, or stops. Balancing the Segway is possible because gyroscopes and other sensors constantly sense a person's center of gravity and make minute adjustments to ensure a balanced and upright posture.[1]

The Segway is marketed as a revolutionary device that requires no special skills and that "virtually anyone can use."[1] Currently, it is being used in a variety of government, airport, and university settings as a transportation alternative to combustion engine vehicles.[1,2] The Segway has been marketed to people as an alternative transportation device that can replace the automobile on short trips and commutes of less than 20km.[1,3]

Although the Segway provides an alternate method of transportation, the inventor of the device, Dean Kamen, states that the Segway was not designed as a mobility aid for disabled populations.[1] Another device, the Independence iBOT 3000 Mobility System,[4] was designed by Kamen for this purpose. The iBOT can perform many functions that a standard wheelchair cannot, such as climbing stairs and curbs; however, its $30,000 price may be prohibitive for most potential users.

Although there are no peer-reviewed articles regarding the Segway as a mobility aid for disabled populations, there are many personal accounts posted on the Internet by people with disabilities who use it for mobility purposes. These people include those with Parkinson's disease, multiple sclerosis, amputations, arthritis, cerebral palsy, postpolio syndrome (PPS), chronic fatigue syndrome, spinal cord injury (SCI), fibromyalgia, and hip replacement.[5]

These accounts also report that the Segway provides disabled people with a higher quality of life.[6,7] Many such people who use it believe that they do not need the high level of assistance provided by a scooter or power wheelchair. Despite any difficulties they may have in walking distances, they can stand; consequently, the Segway truly matches with their abilities and maximizes their health and independence.[5] The Segway travels at faster speeds, takes up much less space, is more maneuverable, and rides more easily on uneven terrain than does a typical scooter or power wheelchair.[8] Because people can stand upright on it, visibility in busy areas is better for the rider and for others around them; also, weight bearing on the lower extremities when riding it is important for maintaining bone density.[9] Users with a disability also claim they have better digestion and circulation as a result of their upright posture when riding the device.[7]

Segway users report that socially, there are fewer stigmas associated with using it for transportation than there are when using a wheelchair or scooter.[6,7] The Segway is not regarded as a medical device and therefore users believe that it does not attract attention to their disability.[7] For some people, the Segway restores "a great sense of hope and meaning" in their life.[6] One person explained that when he uses his Segway, he is no longer "at fire hydrant height, [but] at human being height."[7] Powerful statements such as these demonstrate the need for

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more research into the appropriateness of the Segway as a safe alternative to other mobility aids.

Currently, there are no standard assessments with which to determine a person's suitability for power mobility.[10] Generally, evaluations for power mobility consist of cognitive indicator tests and performance tests that assess a patient's ability to access the mobility device, to operate it safely, and to negotiate environmental obstacles.[11,12] Evaluation also includes assessment of items such as medical history and prognosis, the home environment, lifestyle needs, transportation methods, equipment needs, funding issues, the patient's goals and expectations, and his/her physical dimensions, posture, strength, range of motion, skin integrity, sensation, balance, visual field, and the level of assistance needed for transfers.[13] By compiling this information, a therapist can help prescribe appropriate power mobility for a particular patient's needs.[14] If the Segway is to be considered another mobility option, a similar evaluation must be developed before it can be prescribed as a viable alternative to power wheelchairs and scooters.

Our purpose in this study was to determine the functional abilities that are necessary for successful use of the Segway as a mobility device by people with disabilities, and to determine the functional measure(s), if any, that correlate with skills level. The experiences of study participants' in using the Segway were also explored to look further into its realistic use as a mobility device.

METHODS

Participants

Participants were recruited through contact with practicing physiotherapists and occupational therapists from both inpatient and outpatient clinics at our provincial rehabilitation center, as well as through posters and a public interest story on a local television news station. Clinics targeted for this study provide services to people with SCI, stroke, PPS, neuromuscular disorders, arthritis, and amputations. To be included in the study, participants were required to be aged 19 to 65 years, have a good understanding of the English language, and have sufficient cognitive capacity to follow instructions. They were also required to be able to walk 6m either independently or with assistance and to have some functional impairment that required them to consider using an assistive device for mobility. Subjects were excluded from the study if they could not stand independently, or were at high risk for osteoporosis, or if they scored less than 24 on the Cognitive Capacity Screen Examination (CCSE).[15] The local university and hospital human subjects ethics boards approved the study.

Instrumentation

A preliminary interview was developed to collect each participant's demographics, including age, height, weight, sex, medical diagnosis, and the current mobility device being used.

The Berg Balance Scale (BBS), hand grip strength using a Jamar hand dynamometer,[b] manual muscle testing of muscles involved in standing (quadriceps, hamstrings, gluteals, gastrocnemius) and the Timed Up & Go (TUG) test were used to assess functional ability.[16-18] The CCSE was administered at the first session to determine baseline cognitive ability.[15]

This study's principal investigators (BS, ID) developed the Segway Task Assessment tool to determine the participants' capacity to safely drive the Segway (see appendix 1). This tool has not yet been examined for reliability and validity because this study is the first to examine the clinical use of the Segway.

One skill component of operating the Segway that was recorded but not included in the scoring of the Segway Task Assessment was the ability to get on and off the device. This was omitted because we felt that it must first be determined if people with disabilities can drive the Segway before dealing with the challenge of getting on and off the device. Strategies to get on and off evolved over time and reflected the individual preferences and intuitions of each participant, rather than just his/her physical ability.

We also developed a questionnaire intended to elicit the participants' experiences and ideas of usability of the device in their own life. The questionnaires were given to subjects to take home. Answers to the questions were scored on a 5-point Likert scale (1 [strongly agree] to 5 [strongly disagree]) for the following statements: (1) I see the Segway Human transporter as a highly useful mobility aid; (2) A Segway sells for from $5000 to $7000. I am considering buying a Segway; (3) Some people have stated that they feel "less disabled" when using the Segway when compared to other mobility aids. Do you agree with this statement?; and (4) I see limitations to the Segway as a mobility device. A fifth question was open-ended and asked: "How did you feel being on the Segway?" The questionnaire also provided space for comments.

Procedure and Data Collection

All participants read and signed informed consent forms before taking part in the first training session.

Participants underwent 3 training sessions on the Segway in a local rehabilitation gymnasium and under the supervision of the same physiotherapist (KH).

Session 1. The first training session lasted approximately 90 minutes. The physiotherapist collected demographic information from the participants and used specific functional assessments to determine their cognition, balance, functional mobility, muscle strength, and hand-grip strength. Training on the Segway included learning basic skills (eg, getting on and off, going forward and backward, turning). Subjects wore a cycling helmet and 2 spotters were with them at all times. Participants were helped on and off the device if help was needed.

Session 2. If the participant wanted to continue in the study, he/she returned within 1 week for a second training session. This 30-minute session included review of skills learned in session 1 and training in more advanced skills, such as traveling up and down ramps and negotiating varied terrain (eg, grass, curb cuts, tree roots, bumps, and uneven pavement and terrain). During this session, tasks were done indoors (gym) and outdoors (courtyard area at the rehabilitation center). Skills were taught on an incremental basis, from relatively easy to more difficult. Curb ascents and descents were optional.

Session 3. The third session was approximately 40 minutes long and took place within 1 week of the second session. The participants had 15 minutes of skill review and then completed the Segway Task Assessment administered by investigators (BS, ID) who were blinded to each subject's progress during training. Each item on the task list was scored and a total "capability" score was tabulated. Participants were then given the questionnaire that asked about their experiences on the Segway.

Data Analysis

This was a pilot study, thus the primary statistical analysis was descriptive. Our purpose, however, was to look at factors that would predict a person's ability to use a Segway. Our data analysis included (1) a univariate analysis of each outcome

measure using the Segway Task Assessment score as the dependent variable, and (2) a multiple regression analysis using factors that appeared to be related to a high score on the Segway Task Assessment. We anticipated that these results could then be used to develop a cutoff score for determining who might be capable of handling the Segway.

Likert scale questionnaires were analyzed for percentage frequency of answers and for descriptive themes in order to understand the experience of using a Segway. Two investigators (SL, SR) independently coded the information gleaned from the questionnaire.

RESULTS

Twenty-seven subjects, ages 21 to 65 years, were initially recruited for this pilot project that continued over an 8-month period. Twenty-three participants completed all 3 sessions, and 4 people were excluded or withdrew from the study. Of these 4, 2 did not attend the sessions, 1 had a history of osteoporosis, and 1 felt discomfort after the first session and withdrew. The remaining participants included 15 men and 8 women whose mean age was 45.2 years. Primary mobility aids varied for each subject according to his/her needs and included prostheses, manual wheelchairs, canes, forearm crutches, walkers, leg and knee braces, and scooters. Five participants did not use aids. Three participants had more than 1 secondary aid. The subjects' medical conditions and the time since their condition was diagnosed varied widely, and are summarized in table 1.

Assessments

Berg Balance Scale. The range of scores for the BBS was 7 to 56, which is a substantial range in balance ability. The median score was 42.13. Of the 3 participants with the lowest Berg scores, 2 were paraplegic and the other had a spinal cord lipoma. These 3 participants did not use their mobility aids (knee-ankle-foot orthoses and forearm crutches) during the assessment in order that we could obtain a true reflection of their function. Three other participants, however, were permitted to wear their aids (prostheses and a Swedish knee cage to prevent hypertension of the knee) during the BBS assessment because they would use the device when operating the Segway. Table 2 summarizes the assessment scores.

Table 1: Medical Diagnosis of Participants and Years Since Injury or Diagnosis

Medical Diagnosis	Subjects (N=23)	Years Since Diagnosis or Injury
Amputee		
Bilateral: above knee and below knee (n=1)	2	1y, 4y
Unilateral: below knee (n=1)		
Incomplete SCI		
C1-2 ASIA grade D (n=1)		
C4-5 ASIA grade D (n=2)	4	7mo to 23y
C5-6 ASIA grade D (n=1)		
Complete SCI		
T5 ASIA grade B (n=1)		
T9 ASIA grade A (n=1)	2	3y, 31y
Multiple sclerosis	6	6–18y
Guillain-Barré syndrome	1	7mo
Rheumatoid arthritis	1	10y
Spondyloepiphyseal dysplasia	1	32y
Cervical myelopathy	1	2y
Muscular dystrophy	1	33y
Spincocerebellar ataxia	1	6y
Spinal meningitis	1	43y
Spinal cord lipoma	1	31y
Stroke/C5 fracture	1	<1y since stroke

Abbreviation: ASIA, American Spinal Injury Association.

Table 2: Evaluation of Preliminary Assessments

Evaluation Tool	Range	Median	Normative Values
BBS	7–56	42.13	57
Hand strength (kg)			
Right	0.00–56.67	32.07	37 (women)
Left	7.33–53.33	27.67	63 (men)
Manual muscle testing			
Quadriceps			
Right	0–5	4.25	5
Left	0–5	4.18	5
Hamstrings			
Right	0–5	3.48	5
Left	0–5	3.28	5
Gluteals			
Right	0–5	3.89	5
Left	0–5	3.61	5
Gastrocnemius			
Right	0–5	3.57	5
Left	0–5	3.38	5
TUG test (s)	7.9–93	19.12	10
CCSE	26–30	29.22	30
Segway Task Assessment			
Required elements	22–24	23.73	24
Advanced skills	3–8	7	8

Grip strength. The range of grip strength for the right hand was 0.00 to 56.67kg (median, 32.07kg), and for the left hand it was 7.33 to 53.33kg (median, 27.67kg). The Segway's hand control is on the left side and requires grip strength to steer the device. By moving the hand control to the right side, it was possible for 1 participant with very weak left hand grip strength to steer the Segway with his right hand.

Manual muscle testing. The ranges of scores for manual muscle testing were between 0 and 5 for all muscles used in standing (quadriceps, hamstrings, gluteals, gastrocnemius). Two participants, both with SCI (T5, T9-10), felt no contractile activity in the gravity-eliminated position. Two participants had bilateral lower-extremity amputations and therefore, manual muscle testing was not applicable for these subjects.

TUG test. The results from the TUG test also had a wide range of 7.9 to 93 seconds. Thirteen participants used mobility aids during the assessment and 10 did not.

Cognitive Capacity Screening Examination. The range for the CCSE was from 26 to 30 (median, 29.22). No participants were excluded from the study based on their CCSE.

Segway Task Assessment. The range of scores for the Segway Task Assessment was 22 to 24 (median, 23.73). The range of scores for the "optional skills" was 3 to 8, with a median score of 7.

Nine participants were completely independent in getting on and off the Segway; 10 had to lean the device on a wall for stability; and 4 needed the therapist's assistance.

Questionnaire. Twenty participants returned their questionnaires. The frequencies of responses for each Likert question are presented in figure 1.

Statistical Analysis

Assessment data. A statistician was consulted after 23 participants were enrolled and it was discovered that the Seg-

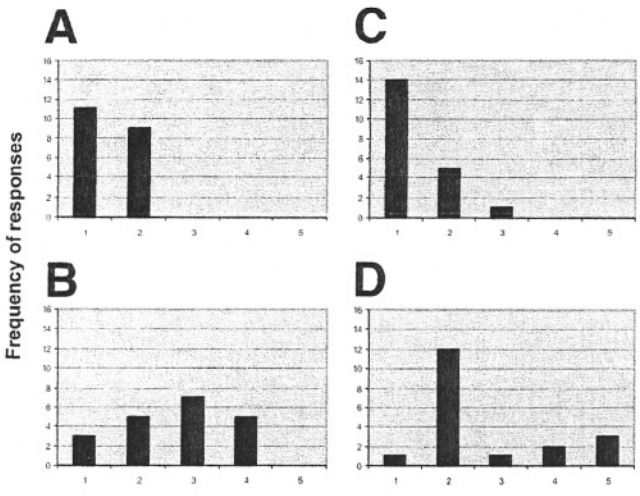

Fig 1. Frequency of answers for Likert scale questions. (A) I see the Segway as a highly useful mobility aid. (B) A Segway sells for $5000 to $7000. I am considering buying a Segway. (C) Some people state that they feel "less disabled" when using the Segway when compared to other mobility aids. Do you agree? (D) I see limitations to the Segway as a mobility device. Legend: 1, strongly agree; 5, strongly disagree. NOTE. One participant did not answer question D.

way Task Assessment tool had reached a ceiling effect. All participants, regardless of their scores on the preliminary assessments, completed the mandatory Segway tasks successfully.

Because there was no variability in the Segway score of the 23 subjects, the statistician suggested the study be terminated early because the addition of more subjects would not enhance the results. Thus, we did not do a regression analysis of the pre-assessment scores and the Segway Task Assessment scores.

Questionnaire data. Four main themes emerged from the data: usability of the Segway; benefits of the Segway; barriers to using a Segway; and performance of the Segway when compared with current mobility options.

DISCUSSION

Functional Assessment

This study demonstrated that there was no correlation between the participants' functional scores and performances on the Segway. Although the functional measures we used may not be predictive of successful Segway use, valuable information was gained by the high level of success of all the participants on the Segway Task Assessment. The participants' disabilities and functional abilities varied widely; therefore, it could be concluded that the Segway may be an appropriate mobility device for a broader range of disability groups and functional levels than first realized.

The Segway Experience

The themes that emerged regarding usability, benefits, barriers, and performance of the Segway provide valuable insight into the realistic use of this device as a mobility aid.

Usability of the Segway. Results from the Segway Questionnaire revealed that all participants felt that the device is a highly useful mobility aid. Participants reported that they would use it for a variety of activities in which they were currently limited because of their disability. These activities included shopping, working, going to school, and going to appointments. Many recreational uses for the Segway were also suggested, such as going to the park, going for walks, going camping, visiting family and friends, and going to a coffee shop. These comments indicated that participants felt that the Segway could promote independence in self-care, productivity, and leisure and might enable them to become more involved in meaningful occupations.

Benefits of the Segway. The benefits of using the Segway as perceived by the participants were consistent with personal accounts previously described by other users with disabilities.[6,7] Our participants believed that their disability was less visible when they were riding the Segway and that they were, at times, able to forget their mobility impairments. Some participants stated that minimizing the visibility of their disability increased their self-esteem and gave them a greater sense of independence. One person dramatically summed up his experience on the Segway by declaring it was "In a word—freedom."

Similar to previous personal accounts regarding posture on the Segway,[7] many of our participants reported that standing on the mobility aid was a huge benefit, compared with sitting when using their current mobility device. They stated that it was good to be standing because they could "look people in the eye," as well as see everything around them. One subject also felt that "being higher up than a scooter or a wheelchair helped with self-esteem."

Barriers to using the Segway. The Segway Questionnaire also asked about barriers that the subjects experienced when using the Segway.

Many participants stated that the device's cost and the lack of funding by insurers was a major limitation to using the Segway. One subject concluded that it was too expensive to purchase, stating, "There are other mobility devices that are less costly, though [the Segway] is the best mobility device I've seen."

The Segway's design also presented limitations. Some participants had difficulty getting on and off it, while others experienced leg weakness and felt that they did not have the standing tolerance to use it for long periods of time. Other barriers included a lack of storage for carrying items, its weight and size (for storage and portability), the life of its battery, and terrain and weather limitations. The risks of theft, loss, and repair were also mentioned as obstacles to owning a Segway. One final issue raised by participants was that of civic bylaws governing the use of the Segway in public spaces (ie, on public transit systems, on sidewalks). For the Segway to become a viable mobility aid for people with disabilities, these limitations will need to be addressed. The obstacles discussed in this study can enlighten people involved in Segway research and reveal further research opportunities.

Performance of the Segway. The performance of the Segway when compared with other mobility devices was another important theme that emerged from this study. Most participants believe that the Segway has features that make it more desirable than their current mobility options. Several wheelchair users thought the Segway was more maneuverable than their wheelchairs. One person stated that it had "the ability to turn on a dime." Participants also thought that they could go farther and faster on the Segway and felt that it was more stable than other mobility aids. One subject stated, "I can move with speed and agility without having to care about my balance. I am 10 times more stable on a Segway than with my walker." Some of these claims of enhanced performance may stem from the fact that several subjects used manual mobility aids and therefore were not accustomed to the freedom a power mobility option can provide. The results, however, indicate that the Segway should be considered as a mobility option for people

with disabilities because it offers improvements over other available mobility aids.

Study Limitations

We recognize that there are limitations to this study. The Segway Task Assessment was not sensitive enough to capture the full range of participants' capabilities on the Segway. Consequently, data analysis of participants' abilities to use the device resulted in a ceiling effect. The inconsistent use of mobility aids during the initial assessments (BBS, TUG) was another limitation; some participants used assistive devices during the assessments and some did not.

Another limitation is that participants were self-recruited. We reached people with a broad range of abilities and mobility impairments with this method of sampling and our results show a high degree of variability because of that. This may be seen as a limitation in terms of predicting the use of the Segway for a particular population, but we see this as a strength factor because it means our findings can be generalized to a larger population and it speaks to the clinical utility of the results.

Self-recruitment requires that potential participants initiate contact with the study coordinator. As such, the sample in this project may not be representative of the entire population that may have the functional ability to use the Segway. Thus, our study has a self-selection bias. People with cardiopulmonary disease represent 1 population that may have been missed because of self-recruitment. Inclusion criteria was stated on recruitment posters as "You have a disability that makes walking long distances difficult or impossible." We believed that this statement would encourage people who thought they could benefit from the Segway to contact the coordinator. Perhaps replacing "disability" with "condition" in recruitment of participants for future studies will encourage other populations to participate.

Finally, it would have been ideal to have participants familiarize themselves with the Segway in their regular home environment. Had participants been able to use the Segway at home for a suitable time period (ie, 2wk), they would have been able to better express how it could fit into their daily lives. This was not an option for the study, however, because of safety precautions.

Further Research

As a result of the ceiling effect that occurred in this study, we have developed a second phase in order to complete a more detailed analysis of Segway use. The purpose of phase II is to determine if the Segway would be a better device for people with disabilities than their current assistive devices. We are using an outcome measure that specifically assesses how well their current devices meet their mobility goals. This research will help to establish the Segway's potential as a power mobility option.

CONCLUSIONS

This preliminary study has shown that the Segway is a useful device for populations with a range of functional disabilities. Our results indicate that using a Segway may increase personal mobility for some people with functional limitations. This would enable them to become more involved in meaningful activities, and therefore it has the potential to increase one's self-esteem and quality of life. Through continued research, the potential of the Segway to be a viable mobility option for people with disabilities may become a reality.

Acknowledgment: We thank Ruth Milner, MSc, for her statistical analysis.

APPENDIX 1: SEGWAY TASK ASSESSMENT

Getting on the Segway	☐	Independently, no aids
	☐	Independently, against wall/blocks
	☐	Requires assistance from 1
	☐	Requires assistance from 2
Getting off the Segway	☐	Independently, no aids
	☐	Independently, against wall/blocks
	☐	Requires assistance from 1
	☐	Requires assistance from 2

Mastery of skills:			**Score**
Straight forward	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Straight backward	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Stand still	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Turn right	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Turn left	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Follow a line (the basketball key) turning to the left	☐	Yes	2
	☐	Somewhat (wheel touches/crosses line 1–5×)	1
	☐	No	0
Follow a line (the basketball key) turning to the right	☐	Yes	2
	☐	Somewhat (wheel touches/crosses line 1–5×)	1
	☐	No	0
Uphill	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Downhill	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Through doorway (the one from gym to hall near Ian's office)	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
On grass (figure 8 around trees—model the path first)	☐	Yes	2
	☐	Somewhat (subject starts and stops)	1
	☐	No	0
Over rough terrain	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Overall impression (around loop)	☐	High pass	2
	☐	Pass	1
	☐	Fail	0
Required Skills Score			___/24
Up mat curb: 1 mat (optional)	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Up mat curb: 2 mats (optional)	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Up mat curb: 3 mats (optional)	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
Down 3" curb	☐	Yes	2
	☐	Somewhat	1
	☐	No	0
		Advanced Skills Score	___/8

NOTES: _____

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Suppliers

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