Cardiovascular Responses to Submaximal Concentric and Eccentric Isokinetic Exercise in Older Adults

Elizabeth Thompson, Theo H. Versteegh, Tom J. Overend, Trevor B. Birmingham, and Anthony A. Vandervoort

Our purpose was to describe heart rate (HR), mean arterial blood pressure (MAP), and perceived exertion (RPE) responses to submaximal isokinetic concentric (CON) and eccentric (ECC) exercise at the same absolute torque output in older adults. Peak torques for ECC and CON knee extension were determined in healthy older males (n = 13) and females (n = 7). Subjects then performed separate, randomly ordered, 2-min bouts of CON and ECC exercise. Heart rate and MAP increased (p < .001) from resting values throughout both exercise bouts. CON exercise elicited a significantly greater cardiovascular response than ECC exercise after 60 s. Peak HR, MAP, and RPE after CON exercise were greater than after ECC exercise (p < .01). At the same absolute torque output, isokinetic CON knee extension exercise resulted in a significantly greater level of cardiovascular stress than ECC exercise. These results are relevant to resistance testing and exercise in older people.

Key Words: isokinetic exercise, submaximal, eccentric, concentric, heart rate, blood pressure, aging

Isokinetic exercise is becoming increasingly popular because it may provide the most efficient and least joint-stressful strength training (Hislop & Perrine, 1967; St. Pierre et al., 1992). These benefits make it a viable exercise option in the older population, where joint stress can be a major concern. Unfortunately, little is known about the cardiovascular stress associated with this form of exercise, although some reports suggest that such stress may be substantial (McMeeken, Nall, McNicol, Goble, & Fleming, 1995; Scharf, Eckhardt, Maurus, & Puhl, 1994; Solomon, 1992). Fitness and rehabilitation professionals are thus faced with the dilemma of providing effective resistance exercise treatment to an older population whose cardiovascular status might be at risk during such therapeutic procedures.

At present, controversy exists as to whether a cardiovascular examination prior to isokinetic exercise is warranted. Most researchers believe that isokinetic

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exercise should be preceded by cardiovascular screening (Iellamo et al., 1997; McMeeken et al., 1995; Solomon, 1992; Vinson, Lindsay, Mettler, & Murray, 1990), whereas others have suggested that such cardiovascular precautions are not routinely necessary (Haennel et al., 1992; Horstmann et al., 1994). Clinically, it is doubtful that such screening routinely takes place before isokinetic assessments. Little attention has been paid to the differences in cardiovascular responses to concentric and eccentric submaximal isokinetic exercise, and even less to such differences in older adults.

Reduction of muscle strength with aging has been reported in many studies of neuromuscular function, based on isometric (ISO) and isokinetic concentric (CON) strength measurements (Hortobagyi et al., 1995; Vandervoort, 1997). Daily activities, however, also require muscles to develop tension under a third activation condition referred to as eccentric (ECC) loading, where the muscle is lengthened by an external force while attempting to resist, as in going down stairs or the gait cycle (Enoka, 1996). In this situation, the muscle’s physiological capacity is much greater than in either ISO or CON exercise (Enoka, 1996), perhaps due to the increased role played by the muscle’s passive elements. Recent observations have indicated that age-related changes in the neuromuscular system actually enhance a muscle’s ECC performance (Hortobagyi et al., 1995; Porter, Myint, Kramer, & Vandervoort, 1995; Porter, Vandervoort, & Kramer, 1997; Poulin, Vandervoort, Paterson, Kramer, & Cunningham, 1992), although clinical observation indicates that older people have more difficulty performing ECC exercise. Older people are often faced with the challenge of producing an absolute torque output to accomplish a given task. For a given absolute torque output, the ECC type of muscle contraction may require less neural activation and energy consumption than when muscles use ISO or CON contractions (Enoka, 1996; Tesch, Dudley, Duvoisin, Hather, & Harris, 1990). The physiological and functional implications of these differences are important and extensive (e.g., lower heart rate and blood pressure responses during resistance-type exercise).

The purpose of this study was, therefore, to describe heart rate, blood pressure, and subjective perceived exertion responses to submaximal, isokinetic concentric, and eccentric exercise at the same absolute torque output in older adults. Our hypothesis was that for a given absolute torque output, less cardiovascular stress would be produced during eccentric contractions than during concentric contractions.

**Methods**

**GENERAL OUTLINE**

Peak torques for ECC and CON knee extension movements were determined on an isokinetic dynamometer. Heart rate (HR) and mean arterial blood pressure (MAP) were recorded during, and whole body perceived exertion (RPE) after, 2-min bouts of both ECC and CON knee extension exercise at 50% of CON peak torque. Peak HR and RPE were also recorded following a standard 6-min walk test to provide a comparison between submaximal endurance exercise and resistance exercise (Guyatt et al., 1985).
PARTICIPANTS

Twenty healthy, recreationally active (defined as not in formal training for any sport) subjects over the age of 65 were recruited from among volunteers responding to advertisements placed around the University community (Table 1). All subjects were independently ambulatory. Subjects were excluded if they had a history of cardiovascular or other systemic diseases, had any orthopedic or neurological conditions that would preclude exercise, or were taking any medications for heart rate or blood pressure. The study was approved by the University’s ethical research review board, and all subjects provided informed written consent prior to participation.

TEST PROCEDURES

All tests were completed in one visit to a climate-controlled laboratory. After a brief orientation, collection of baseline data for HR and MAP (sitting position), and a stretching warm-up, subjects performed a 6-min walk around a 120-foot indoor measured course. Subjects were told to “Walk as far as you can in six minutes.” Rest stops were permitted, but the clock continued to run during the rest. Immediately following the end of the walk, the walk distance, HR (Polar Vantage XL, Polar Electro Inc., Port Washington, NY), and RPE (Borg, 1982) were recorded. We used the 6–20-point Borg Scale with anchors of very, very light (7) and very, very hard (19). The 6-min walk also served as a general lower extremity warm-up for the subsequent isokinetic exercise.

After a short rest (approximately 15 min), the ECC and CON isokinetic strength assessments were carried out on a Kinetic Communicator (Kin-Com, Model 500-H, Chattec Corp., Chattanooga, TN). Subjects were placed in a seated position (back 80° from horizontal) and were secured to the Kin-Com with belts around the chest, pelvis, and the thigh of the test leg. The dominant leg, defined as the leg with which the subject would kick a ball, was used for all tests. A stool was used to support the non-test leg. The axis of rotation of the Kin-Com was adjusted to be coaxial with the lateral femoral epicondyle. The resistance pad was placed just above the ankle, allowing full dorsiflexion and plantarflexion.

The left arm of the subject was supported on pillows to a level corresponding with that of the heart. The appropriately sized finger cuff of an automated, plethysmographic blood pressure and heart rate monitor (Finapres, Ohmeda 2300, Englewood, CO) was attached to the middle finger of the left hand between the

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<th>Table 1</th>
<th>Descriptive Information on the Subjects</th>
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<td>Gender</td>
<td>Age (years)</td>
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<tr>
<td>Males (n = 13)</td>
<td>74.5</td>
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<td>Females (n = 7)</td>
<td>76.4</td>
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<td>Total (n = 20)</td>
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proximal and distal interphalangeal joints. The Finapres device has been shown to provide valid estimates of changes in intraarterial pressure (Idema et al., 1989; Parati, Casadei, Groppelli, De Rienzo, & Mancia, 1989) and has been used during exercise of different types, intensities, and muscle groups (Iellamo et al., 1997; Imholtz, Wieling, Langewouters, & Montfrans, 1991; Papelier, Escourrou, Gauthier, & Rowell, 1994).

After positioning, and a verbal review of the test procedures, subjects were allowed to practice knee extension movements while the tester emphasized the differences between ECC and CON muscle actions. The specific isokinetic practice (90 deg/s) consisted of 12 repetitions at a perceived effort of 50%, 8 reps at 75%, and 3 reps at 100% perceived maximal effort. Subjects were allowed to rest between each set and again before the actual trials to determine peak torque. Knee flexion and extension movements were performed over a 50° range of motion, from 65 to 15° of flexion. The minimum force required to activate the dynamometer resistance arm was set at 10 Newtons for the test contraction and 0 Newtons to return the limb to the starting position. Subjects were not allowed to grasp the table or the restraining belts during testing. They were also taught to breathe out during contractions to prevent performing a Valsalva maneuver. The Valsalva maneuver, a forced expiratory effort against a closed airway that helps to stabilize the chest and abdomen during heavy lifting, greatly increases intrathoracic pressure, which results in decreased venous return to the heart. An acute increase in arterial pressure results, followed by a marked decrease due to the diminished venous return.

Isokinetic ECC and CON peak torques were determined by averaging the best 3 of 5 maximal trials (Horstmann et al., 1994). A 15-s pause was allowed between each trial. Concentric maximal trials were always performed before ECC. Following each set of maximal trials, subjects rested until HR and blood pressure (BP) returned to baseline levels. After the peak torque determinations, they performed, in random order, two separate, 2-min bouts of ECC or CON exercise at a target torque output of 50% of their isokinetic CON peak torque. A 5-min recovery phase was allowed between the two exercise bouts. A graphic display on the Kin-Com computer screen provided subjects with visual feedback. Verbal encouragement was also provided by the tester. HR and BP (systolic and diastolic) were recorded at 15-s intervals throughout the 2-min tests, and a RPE was obtained at the end of each work bout. Immediately following the end of each 2-min test, subjects again performed 5 maximal contractions (with a 15-s rest between contractions) to determine percent drop-off from preexercise peak torques.

DATA ANALYSIS

Systolic (SBP) and diastolic (DBP) blood pressures were measured using the Finapres, and MAP was calculated: MAP = DBP + (SBP – DBP). We also calculated the rate-pressure product (RPP = HR × SBP × 10⁻²) as an index of myocardial oxygen consumption (Nelson et al., 1974). All statistical procedures were carried out using a statistical package (Statistica for Windows, Release 5.1, Statsoft, Inc., Tulsa, OK). The critical value for significance for all comparisons was set at \( p < .05 \). Separate two-way analysis of variance (ANOVA) tests (2 modes of exercise by 9 sampling times), with repeated measures on both factors, were used to compare HR, MAP, and RPP responses during the bouts of ECC and CON exercise. Significant \( F \) ratios were followed by pairwise comparisons using Scheffé post-hoc tests.
Peak HR and RPE responses during the 6-min walk and the 2-min ECC and CON exercise bouts were then compared using one-way repeated measures ANOVA tests. Pearson Product Moment correlation coefficients were used to examine the interrelationships among the distance covered in the 6-min walk and the peak isokinetic ECC and CON torques.

**Results**

All subjects completed all procedures without incident. Baseline HR (69.3 b·min⁻¹) and MAP (91.1 mm Hg) were within normal ranges for this age group. Peak torques before and after the 2-min bouts of isokinetic CON and ECC knee extension exercise are presented in Table 2. Eccentric peak torque was significantly greater than CON peak torque both before and after exercise. Peak torque post exercise decreased 17.7% for CON exercise and 1.6% for ECC exercise.

There was a significant interaction between HR and Time for exercise type ($F = 9.75, p < .001$) (Figure 1). Post-hoc analysis indicated that both CON and ECC exercise produced significant increases in HR from Time 0 to 120 s ($p < .001$). The HR during CON exercise became significantly greater than ECC exercise at 60 s ($p < .001$), and this difference was maintained until the end of the 2-min exercise bout.

There was also a significant interaction between MAP and Time for exercise type ($F = 8.67, p < .001$) (Figure 2). Both CON and ECC exercise produced significant increases in MAP from Time 0 to 120 s ($p < .001$). The MAP during CON exercise became significantly greater than during ECC exercise by 60 s ($p < .001$) and this difference was also maintained until the end of the 2-min test.

Peak HR, MAP, RPP, and RPE data after the 2-min bouts of CON and ECC exercise, and HR and RPE after the 6-min walk test (6-MWT), are presented in Table 3. Peak HRs after CON and 6-MWT exercise were significantly greater than after ECC exercise ($p < .01$). Mean arterial blood pressure and RPP after CON exercise were significantly greater than after ECC exercise ($p < .01$). Peak RPE after CON exercise was significantly greater than after ECC or 6-MWT exercise ($p < .001$).

There was a positive correlation between 6-MWT distance (±SD = 546 ± 65 m) and both CON ($r = .56, p = .010$) and ECC ($r = .55, p = .012$) preexercise peak torque as well as between preexercise CON and ECC peak torque ($r = .86, p < .01$).

**Table 2** Peak Torques Before and After 2-Min Bouts of Isokinetic Concentric and Eccentric Knee Extension Exercise at the Same Absolute Torque

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<th>Concentric</th>
<th>Eccentric</th>
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<td>$M$</td>
<td>$SD$</td>
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<tr>
<td>Before</td>
<td>111.0</td>
<td>36.8*</td>
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<td>After</td>
<td>91.4</td>
<td>30.2</td>
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*Significantly greater than After value. **Significantly greater than Concentric value.
Figure 1. Heart rate (HR) (bpm) versus Time (s) during the 2-min concentric and eccentric exercise bouts at a torque output of 50% concentric peak torque. HR at Time 0 represents resting HR.
* Concentric HR significantly greater than eccentric HR ($p < .001$).
+ HR value significantly greater than resting HR ($p < .001$).

Figure 2. Mean arterial blood pressure (MAP) (mm Hg) versus Time (s) during the 2-min concentric and eccentric exercise bouts at a torque output of 50% concentric peak torque. MAP at Time 0 represents resting MAP.
* Concentric MAP significantly greater than eccentric MAP ($p < .001$).
+ MAP value significantly greater than resting MAP ($p < .001$).
Discussion

To our knowledge, this is the first study in which HR and MAP responses to both concentric and eccentric submaximal isokinetic exercise have been examined in older adults. The majority of previous studies that have addressed the cardiovascular effects of isokinetic exercise involved maximum effort concentric exercise protocols in younger subjects (Greer, Dimick, & Burns, 1984; Haennel et al., 1992; Horstmann et al., 1994; McMeeken et al., 1995; Solomon, 1992; Vinson et al., 1990). Differing measurement techniques, experimental protocols, and age groups thus make it difficult to compare our results with those of previous studies.

We observed significant increases in HR and MAP from baseline values during both eccentric and concentric exercise bouts. Similar increases following isokinetic concentric knee extension exercise have been reported previously (Haennel et al., 1992; McMeeken et al., 1995; Solomon, 1992), although the magnitude of our increases is lower because we used a submaximal protocol.

We also observed significant increases in RPP during the exercise bouts with the CON condition producing a higher RPP at the end of the 2-min test. Although this value was not as high as has been reported in previous papers, direct comparisons are difficult, as we calculated RPP after submaximal resistance exercise in older men while previous papers have calculated this variable after maximal concentric work in younger males (Haennel et al., 1992; Solomon et al., 1992; Vinson et al., 1990).

Heart rate and MAP during concentric exercise became significantly greater than for eccentric exercise starting at 60 s and continuing to the end of the 2-min exercise bout. Only one previous study has compared responses to both eccentric and concentric isokinetic exercise. Horstmann et al. (1994) studied HR and MAP responses to 1 min of maximal concentric (180 deg/s) and eccentric (60 deg/s) knee flexion/extension exercise in male subjects between 22 and 60 years of age. They observed greater cardiovascular system responses to concentric exercise (with a more pronounced response in younger subjects), and attributed this partially to the

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<th>Table 3 Heart Rate, Mean Arterial Blood Pressure (MAP), Rate-Pressure Product (RPP), and Ratings of Perceived Exertion (RPE) (Means and SD) After Concentric, Eccentric, and Walking (6-MWT) Exercise</th>
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<td>Heart rate (b · min⁻¹)</td>
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<tr>
<td>Concentric</td>
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<td>Eccentric</td>
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<td>6-MWT</td>
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¹Systolic/diastolic blood pressure for concentric was 208/112, and for eccentric, 180/70.
²On the 6-20-point RPE scale, 15 is represented by hard, 13 by somewhat hard, and 9 by very light.
*Significantly greater than Eccentric value. **Significantly greater than 6-MWT value.
higher angular velocity during the concentric test. Other studies, however, have reported that the velocity of the movement has no effect on the resulting cardiovascular response (Haennel et al., 1992; McMeeken et al., 1995). We used the same angular velocity for both eccentric and concentric modes of exercise. The absolute increases in HR in our study were smaller, due probably to our submaximal exercise protocol, but the increase in systolic blood pressure was approximately the same. We measured BP continuously via an automated system while Horstmann et al. took a manual measurement at the end of their exercise bout. Blood pressure has been reported to decrease precipitously following exercise (MacDougall, Tuxen, Sale, Moroz, & Sutton, 1985; Scharf et al., 1994), thus Horstmann et al. may have missed the peak BP in their subjects. Accurate BP measurement during dynamic exercise is problematic, and the issues have been recently reviewed (Griffin, Robergs, & Heyward, 1997).

Only one previous study has addressed the cardiovascular responses to submaximal isokinetic exercise. Iellamo et al. (1997) compared BP and HR responses to 60 s of submaximal isometric and concentric isokinetic and isotonic knee extension exercise in 10 healthy young males. The intensity of the isotonic and isokinetic exercise was set at 40% of peak torque for the respective contraction type, and the isokinetic contractions were performed at an angular velocity of 180 deg/s. The Finapres device was used for continuous blood pressure monitoring during the exercise bouts. Rapid and marked increases in both BP and HR during the concentric isokinetic exercise were reported. Peak MAP reached 145 mm Hg and peak HR was 132 b·min⁻¹. The MAP value is comparable to the value reached in our study, while the higher HR is probably due to the fact that Iellamo et al. studied young men.

The exercise pressor response has been defined as all the cardiovascular changes that serve to increase mean arterial pressure during a muscle contraction (Mitchell, Kaufman, & Iwamoto, 1983). The magnitude of increase in HR and BP is related to the exercise intensity and duration, as well as the size of the active muscle mass (Buck, Amundsen, & Nielson, 1980; Lewis et al., 1985; Seals, Washburn, Hanson, Painter, & Nagle, 1983). Thus, due to an increase in the excitation of muscle afferent receptors (Mitchell, Payne, Saltin, & Schibye, 1980), greater increases in HR and BP will occur during resistance exercise with a larger muscle mass (Haennel et al., 1992) or at a higher relative exercise intensity.

We made an a priori decision to study CON and ECC exercise at the same absolute intensity, knowing that ECC peak torque would likely be higher than CON peak torque, and thus the cardiovascular and perceived (RPE) stress associated with CON exercise would likely be different. Our decision was based on the greater use of concentric exercise programs used in both rehabilitation and training, and on the greater accessibility of concentric exercise apparatus. Additionally, from a functional perspective, older adults are often faced with the challenge of producing an absolute torque output in order to accomplish a given task, although clinical observation indicates that older adults have more difficulty performing eccentric exercise. Our purpose was to describe the cardiovascular demands associated with both eccentric and concentric methods of producing that given torque.

In our study, the subjects did not work at the same relative exercise intensity during the 2-min exercise sessions. The target torque output for both concentric and eccentric exercise was set at 50% of concentric peak torque. This target torque output was equivalent to 31% of peak eccentric torque. Thus, although the same absolute torque levels were attained during the 2-min exercise bouts, the actual
relative eccentric intensity was considerably less than the concentric intensity. This could explain the difference in HR, MAP, and RPE responses to the eccentric and concentric exercise that we observed in our study. Although our purpose was to describe differences at the same absolute torque output, we did carry out exploratory post-hoc analysis to further investigate this question. We compared the final HR following concentric and eccentric exercise using an analysis of covariance to adjust for the difference in relative intensity. Although there was still a significant effect of exercise (contraction) type on HR (p = .04), it was not as pronounced. Therefore, further research comparing HR and BP responses to the same relative level of exercise intensity (i.e., exercise at 50% of ECC peak torque vs. 50% of CON peak torque) is warranted to provide additional insight into the differences in cardiovascular response to these two types of muscular contractions. The data of Horstmann et al. (1994) for ECC and CON isokinetic knee extension exercise in men suggest that such a difference may exist, at least for maximal work. They reported that a 1-min bout of maximal eccentric knee exercise (60 deg/s) elicited significantly lower heart rate and blood pressure responses compared to the same period of maximal concentric knee exercise (180 deg/s). In contrast, MacDougall et al. (1992) have reported that CON and ECC exercise at the same relative intensity elicited a similar pressor response despite different absolute torque outputs. No previous study has compared cardiovascular responses to submaximal concentric and eccentric isokinetic exercise at the same relative intensity.

Several authors have reported that, at the same power output, energy expenditure during concentric work is significantly greater compared to eccentric work (Abbott & Bigland, 1953; Asmussen, 1952; Knuttgen, Bonde Petersen, & Klausen, 1971). This relationship may also be true for maximal power output as well (Seliger, Dolejš, & Karas, 1980). Concentric exercise has been shown to recruit a larger number of motor units compared to eccentric (Bigland-Ritchie & Woods, 1976; Moritani, Muramatsu, & Muro, 1988; Tesch et al., 1990), thus explaining the increased cardiovascular demand of concentric exercise. MacDougall et al. (1985) reported that BP decreases (from that reached during the lifting phase) during the lowering or eccentric portion of a leg press exercise. Miles, Owens, Golden, and Gotshall (1987) observed that stroke volume and cardiac output increased during lowering movements of leg extension exercise, suggesting a decrease in peripheral resistance. Since negative (eccentric) movements require less muscle activation, the intramuscular forces are reduced and subsequently result in a decrease in BP.

Several clinical implications arise from the present study. We have demonstrated that even submaximal isokinetic exercise results in significant stress on the cardiovascular system in older adults. Previous studies have focused mainly on maximal isokinetic work and, with but one exception (Horstmann et al., 1994), have recommended that caution be exercised before performing isokinetic assessments (Haenel et al., 1992; Ielloamo et al., 1997; McMeeken et al., 1995; Scharf et al., 1994; Solomon, 1992; Vinson et al., 1990), particularly in at-risk populations. Our sample population included healthy, recreationally active older adults who were screened for cardiovascular, orthopedic, and neurological conditions and thus were not representative of a typical older population. Since the risk in an older population is greater given the increased incidence of hypertension and heart disease, the need for a careful cardiovascular screening prior to isokinetic exercise for fitness or rehabilitation may be warranted.
Some recommendations should be followed to reduce the chance of a cardiovascular event during isokinetic exercise. Since thepressor response is related to the amount of exercising muscle mass, stabilizing muscle activity (i.e., use of the arms during lower extremity exercise) should be reduced to a minimum. The Valsalva maneuver should be discouraged, with clients reminded to breathe normally during the contractions. Preexercise screening for hypertension or other cardiac disease should be carried out, particularly before maximal isokinetic protocols, and graduated warm-up and warm-down programs should be provided before and after the exercise. In addition, since eccentric strength is preserved in the elderly (Hortobagyi et al., 1995; Porter et al., 1997; Poulin et al., 1989), and eccentric isokinetic exercise appears to be more protective of cardiovascular responses both in maximal (Horstmann et al. 1994) and submaximal protocols (current study), it may be the most appropriate form of resistance exercise for older adults.

References


with special reference to eccentric strength. *Journals of Gerontology: Biological Sciences, 50A*(6), B399-B406.


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