Journal of Strength and Conditioning Research, 2007, 21(4), 1278–1281

POSTACTIVATION POTENTIATION EFFECTS AFTER HEAVY RESISTANCE EXERCISE ON RUNNING SPEED

DIMITRIS E. CHATZOPOULOS,[1] CHARALAMBOS J. MICHAILIDIS,[1] ATHANASIOS K. GIANNAKOS,[1] KOSTAS C. ALEXIOU,[2] DIMITRIOS A. PATIKAS,[1] CHRISTOS B. ANTONOPOULOS,[1] AND CHRISTOS M. KOTZAMANIDIS[1]

[1]Laboratory of Coaching, Department of Physical and Sport Science, Aristotle University, 54006, Thessaloniki, Greece; [2]Department of Physiotherapy, Lamia, Greece.

ABSTRACT. Chatzopoulos, D.E., C.J. Michailidis, A.K. Giannakos, K.C. Alexiou, D.A. Patikas, C.B. Antonopoulos, and C.M. Kotzamanidis. Postactivation potentiation effects after heavy resistance exercise. *J. Strength Cond. Res. 21(4):1278–1281. 2007.*—The purpose of this study was to investigate the postactivation potentiation effect after a heavy resistance stimulus (HRS) on running speed (RS). Fifteen amateur team game players (basketball, volleyball, handball, and soccer players), ages 18–23 years running the 30-m dash and the intermediate phase of 0–10 and 0–30 m sprints, were used to evaluate RS. Resistance training consisted of 10 single repetitions at 90% of 1 repetition maximum. The running tests were performed 3 times—(a) 3 minutes prior the HRS, (b) 3 minutes after the HRS, and (c) 5 minutes after the HRS—in separated training sessions. Results showed that RS was not affected 3 minutes after the resistance training, but it increased for both selected running phases (0–10 and 0–30 m) 5 minutes after the HRS ($p < 0.05$). These findings indicate that heavy resistance exercise improves 10- and 30-m sprint performance when performed 5 minutes after the exercise bout.

KEY WORDS. strength, sprint, acceleration

INTRODUCTION

Numerous studies in the past have shown that human performance can be affected after exercise either negatively or positively. For example, muscle performance decreases after a fatigue session (6) but increases after warming up with a submaximal (7, 28, 37) or high-intensity session (1, 32). Concerning the last case, muscle performance increased after conditioning tetanus (1, 38), subfusion stimuli (23), or maximal voluntary action (17, 35, 39). The previously mentioned muscle performance augmentation will be mentioned as postactivation potentiation (PAP).

Concerning the voluntary activation, it was reported that maximal isometric contraction (17, 18), high-intensity resistance stimulus (21, 24), ballistic movement with resistance (35), and plyometric exercise (25) had a positive effect on the performance in various tasks. Furthermore, voluntary contractions have been shown to result in PAP for ballistic movements of the lower (12, 15, 16, 40, 41, 42) and upper (17) limbs but not for the peak isometric force or the unloaded shortening velocity (14, 32). However, there are studies that reported no PAP on ballistic movements of lower (33) and upper (20) limbs. Moreover, it was reported that plyometric training can cause PAP for maximal isometric voluntary contraction (25). These conflicting results cited here were attributed to the fact that PAP is influenced by various factors, such as muscle fiber type (32), performance level (15, 42), content of the applied protocol (5), exercise type (30, 35), time interval between the conditioning stimulus and the performance testing, and eventually gender (21) and familiarization (24).

The acute effect of heavy resistance stimulus (HRS) has been extensively studied in jumping (9, 21, 35, 42), but there is only limited information about running speed (RS). Smith et al. (36) reported that maximal cycling performance was positively affected 5 minutes after an HRS (11 trials at 90% of 1 repetition maximum [1RM]). Additionally, McBride et al. (24), reported the presence of PAP on RS in the distance of 30–40 m but not in intermediate distances for the first 30 m after 3 trials of 90% of 1RM. Concerning the previously mentioned studies, it seems that Smith et al. (36) used a more intensive resistance protocol than did McBride et al. (24). Previous studies have also shown that the magnitude of PAP is protocol dependent (5, 17, 35, 39). Based on these findings, McBride et al. (23) speculated that more intense resistance training could affect positively the performance during the acceleration phase as well. For this reason, it seems interesting to re-examine the PAP effect on running after an HRS. Another interesting point is that relevant studies (24, 36) that investigated the PAP effect on running performance had used only a 5-minute interval after HRS. Thus, there is no information on what happens with shorter intervals that presumably are more affected by fatigue. Moreover, considering that fatigue and potentiation coexist (31), it would be interesting to investigate to what extent the previously mentioned mechanisms affect preferential running performance using shorter intervals than 5 minutes.

The main purpose of this study was to re-examine the PAP during running and especially during the early acceleration sprint phases. The secondary purpose was to examine which time interval between HRS and running task is adequate in order to cause higher enhancement of RS.

METHODS

Experimental Approach to the Problem

This study was designed to investigate the effect of the PAP on RS and especially on the acceleration phase. The PAP effect on RS will be evaluated by performing the RS test before and after the HRS. A secondary purpose will be the investigation of the fatigue and PAP interaction on RS. For this reason the sprint tests will be performed 3 and 5 min after the HRS.

Subjects

Fifteen healthy males participated in the study. They filled out a medical history questionnaire and signed an

Table 1. Mean anthropometric and strength values.

Age (y)	Height (cm)	Body mass (kg)	1 repetition maximum back squat (kg)
22 ± 2	186 ± 6	88 ± 3	151 ± 12

informed consent document before the experiment. They were officially amateur team game players (basketball, handball, volleyball, and soccer) with at least 5 years of experience and had regular resistance training 2–3 times per week (Table 1). All subjects were familiar with maximal RS and the back-squat exercise and could squat more than the 150% of their body mass (36). The participants declared that they did not receive any illegal food supplements or medication related to performance. Furthermore, during the testing day, they did not receive any caffeine products, and 1 day before testing, they were instructed to have regular sleep and not to perform any other type of training.

The experiment was conducted in accordance to the ethics guidelines of the Aristotle University of Thessaloniki, Greece. Participants were free to withdraw if they desired. They signed a written consent after being informed about the experimental protocol and the possible risks associated with it.

Testing Procedures

Back Half Squat at 90°. We used the Smith machine, with adjustable brackets, which forces the bar to travel over a predefined path. Participants were set under the bar, in an upright position, looking forward, and grasping firmly the bar with both hands and supporting it on their shoulders. They were instructed to flex their knee at 90° with the trunk tilted slightly forward and the heels kept on the ground. After reaching this position, they returned to the starting position. Knee angle was evaluated with a goniometer, and the brackets were positioned below the bar to prevent any knee flexion above 90°. The position of the brackets was registered for subsequent testing sessions.

1 Repetition Maximum Estimation. Before testing, participants executed specific warm-ups, including 2 sets of 10, 8, 6, and 3 submaximal back half-squat repetitions responding to 50–80% of the self-perceived 1RM. The estimation of the actual 1RM started from a value 5% below the mentioned one by the participants, by increasing the load by 2% after each successful trial. This was continued until the participant failed to lift the load (not able to execute the full range of motion). The interval between repetitions was 3 minutes. For the final estimation of 1RM, 3–6 trials were performed. All testing procedures were supervised and assessed according to the American College of Sports Medicine guidelines (3).

Running Speed. Running speed was evaluated with 3 pairs of photocells and reflectors (Tag Heuer, Marin, Switzerland) connected with an electronic timer. They were placed at shoulder height and were positioned at the start and at 10 m as well as 30 m after. Running trials were executed starting from a standing start position. Before testing, participants performed a general warm-up program including 10 minutes of cycling on a Monark cycling ergometer (Monark, Varberg, Sweden) followed by specific warm-ups including running trials with submaximal and maximal speed. Finally, the running distances of 0–10 and 0–30 m were evaluated. The 0–10-m distance was selected because it is considered to be an indicator of the initial acceleration period of RS (8). Encouragement was given during maximal RS evaluation. The subjects performed 3 maximal trials 3 minutes before the HRS. The best trial was further processed.

The experimental procedure was performed in 3 sessions. During the first one, participants were familiarized with the experimental conditions. The 1RM was estimated followed by familiarization to the running conditions. In the second session, subjects performed 3 maximal 30-m running trials, and the best trial (lower time) was selected for further evaluation (pre-3). After that, the 1RM was readjusted, and 10 single trials at 90% of 1RM were performed. A 3-minute interval was given to eliminate in a higher extend the influence of fatigue occurrence. Three minutes after the heavy resistance training, subjects executed the running test trial (post-3). In the third phase, they performed the same procedure but with a 5-minute interval between the HRS and the RS test (post-5).

During the experiment, subjects used the same shoes and did not participate in any intervention program. The experimental procedure was conducted in the same sport hall area with an ambient temperature varying between 25 and 28° C. The total procedure is presented in Table 2.

Statistical Analyses

Two 1-way analyses of variance (ANOVAs) for repeated measurements were conducted for the 0–10- and 0–30-m running performance, respectively. The dependent variables were the running performance 3 and 5 minutes before the HRS and 3 and 5 minutes after the HRS. A post hoc Bonferroni test determined which measures differed significantly. The level of significance was set at $p \leq 0.05$.

RESULTS

The RS evaluation was performed using time parameters. Means and standard errors for all measures are listed in Table 3. The intraclass correlation coefficients between the trials for 0–10 and 0–30 m were 0.76 and 0.81, respectively, while for the 1RM it was 0.89.

Results for 0–10 m

According to the results, post-5 showed the best score, followed by pre-5, post-3, and pre-3 (Table 3). The ANOVA for repeated measures showed that there was a significant difference between the 4 measures. The Bonferroni test indicated no significant difference between the sprint times that were performed before the HRS (pre-3

Table 2. Event sequence per training session.

First step	Second step	Third step	Fourth step	Fifth step	Sixth step
Warming up for speed	Maximal running speed (RS) evaluation	Warming up for heavy resistance stimulus (HRS)	HRS: 10 × 90% of 1 repetition maximum	Rest	Maximal RS performance

TABLE 3. Means and standard errors of the speed parameters in seconds.

	Distance	
Measure	0–10 m	0–30 m
Pre-3	1.90 ± 0.02	4.52 ± 0.07
Post-3	1.91 ± 0.03	4.54 ± 0.08
Pre-5	1.89 ± 0.03	4.51 ± 0.07
Post-5	1.84 ± 0.02	4.43 ± 0.06

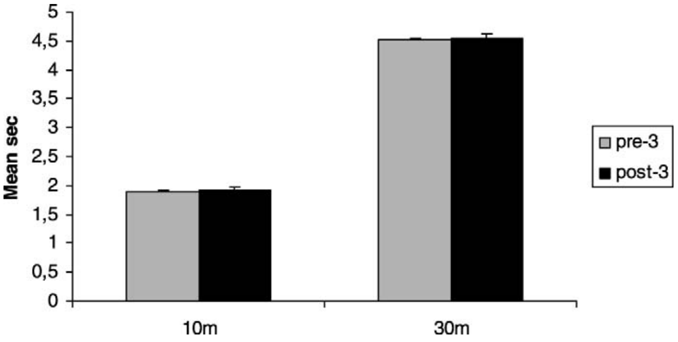

FIGURE 1. Sprint times (in seconds) for pre-3 and post-3 of the selected speed distances.

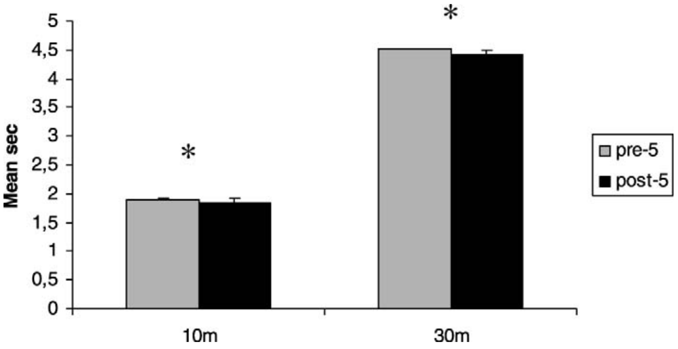

FIGURE 2. Sprint times (in seconds) for pre-5 and post-5 of the selected distances. * Significant difference for $p < 0.05$.

and pre-5). Furthermore, there was no significant difference between pre-3 and post-3 (Figure 1). On the contrary, post-5 was significantly better compared to pre-5 and post-3 ($p < 0.05$).

Results of 0–30 m

Post-5 shows the best score, followed by pre-5, post-3, and pre-3 (Table 3). The ANOVA for repeated measures showed a significant difference between the 4 measures. The Bonferroni test indicated no significant difference between pre-3 and pre-5. Furthermore, there was no significant difference between pre-3 and post-3 (Figure 2). On the contrary, post-5 was significantly better compared to pre-5 and post-3 ($p < 0.05$).

DISCUSSION

The main finding of this study was that RS was increased 5 minutes after the HRS but not after 3 minutes. This positive effect of the HRS on RS was common for the both selected running phases (0–10 and 0–30 m).

These results are in accordance with previous studies that reported that HRS affects oncoming ballistic movements (9), cycling (36), and running velocity (24). This beneficial effect of HRS on the performed tasks has been attributed to PAP (32). Relevant studies have shown that PAP is caused by an augmentation in the rate of phosphorylation in myosin light chain (10) or by an increase in Ca^{2+} kinetics and in the rate of cross-bridge formation (27). Moreover, it was also reported that PAP could be caused by an increase in muscle stiffness (29, 34) or by an enhancement of neuronal output (2, 18, 32, 38) by recruitment of faster motor units. To what extent the previously mentioned mechanisms can explain our findings is beyond the scope of the current study.

The current results revealed no enhancement in the tested running variables 3 minutes after the HRS. A possible explanation could be the fact that after an HRS, both fatigue and PAP coexist (31). During a fatigue test, despite the torque decrement, twitch torque and Ca^{2+} kinetics increase (31). Our findings support the fact that during the first 3 minutes after HRS, the fatigue effect is more dominant than PAP. This explanation is supported by similar findings of previous studies related to jumping performance that used similar short intervals (11) between HRS and task performance. On the contrary, according to the results of this study, a beneficial PAP effect was shown on RS 5 minutes after HRS. The PAP effect could be attributed to the assumption that a 5-minute recovery period between HRS and a running task is enough to reduce the fatigue effect on RS. This assumption could be based on previous studies that have shown that a period of 4–5 minutes (5) is required to restore creatine phosphate and that the PAP effect lasts from 5–20 minutes after HRS (17).

An interesting finding of the current study was that the acceleration phase of RS (distance 0–10 m) was also improved 5 minutes after the HRS. This finding contradicts McBride et al. (24) study, where a positive effect was observed in the distance of 30–40 m but not 0–10 m. McBride et al. (24) explained their result as due to the performance differences between the selected distances of RS. Actually, the 0–10-m distance in RS is considered to be the phase of initial acceleration having distinctive differences with the phase of maximal running velocity both in the muscle activation level and in kinematic parameters (8, 26). Furthermore, McBride et al. (24) observed an increased tendency, though not a significant one, in the intermediate phases of RS. These authors speculated that a more intense resistance protocol could probably affect positively the acceleration phase (0–10 m), and our findings support this. This is also in accordance with previous studies reporting that the intensity (35), duration (39), and number of trials (5, 17) could affect PAP. Moreover, Smith et al. (36), who used a protocol similar to the one used in the current study, reported that such HRS is appropriate for PAP in RS.

Furthermore an interesting issue is the duration of the PAP effect on RS. Generally, based on findings of H-reflex measurements, the PAP effect lasts 15 minutes (17). Regarding RS, it was reported that it increases 5 minutes after HRS but disappears 20 minutes after (36). In a recent study where RS was measured every 3 minutes after HRS, it was shown that after 6 minutes, the PAP effect lasted for 12 minutes, but it was not measured further (4). However, in the same study, the RS measurements were performed in the same training session, and for this reason it is not clear to what extent the performed sprint trials contributed to the PAP effect. From this point of view, it would be important that the duration of the PAP effect be re-examined, measuring each RS trial on different days and with different interval.

In summary, the obtained results indicated that the application of an HRS before running could affects positively the RS. Moreover, the application of an appropriate HRS and an optimal time interval after HRS could have a positive common effect on all running phases.

Practical Applications

The obtained results indicated that HRS prior to RS execution improves sprint performance, and this should be taken into account when evaluating running performance. Moreover, it seems that speed training could be combined with heavy resistance training in the same training session. This case was confirmed with positive results in previous studies concerning jumping performance (11, 13) and RS (22). Furthermore, the HRS could be used for RS enhancement during training or competition.

References

1. Abbate, F., A.J. Sargeant, P.W.L. Verdijk, and A. De Haan. Effects of high-frequency initial pulses and posttetanic potentiation on power output of skeletal muscle. *J. Appl. Physiol.* 88:35–40. 2000.
2. Allmann, L.H. Maximalkraft und Sprintleistung- Maximalkrafttraining im Sprinttraining. In *Grundlangen des Maximal- und Schnellkrafttrainings.* M. Buhrle, ed. Schondorf: Hofmann, 1985. pp. 172–180.
3. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription* (6th ed.). Baltimore: Williams & Wilkins, 2000.
4. Antonopoulos, C., L. Rizaleou, K. Xristoforidou, A. Giannakos, and G. Zaggelidis. The duration of the post activation potentiation of a heavy resistance training on running velocity. *Stinda Sportului (Sport Science).* 55:87–99. 2006.
5. Behm, D.G., D.C. Button, G. Barbour, J. But, and W.B. Young. Conflicting effects of fatigue and potentiation on voluntary force. *J. Strength Cond. Res.* 18:365–372. 2004.
6. Behm, D.G., and D.M.M. St-Pierre. Effects of fatigue duration and muscle type on voluntary and evoked contractile properties. *Eur. J. Appl. Physiol.* 82:1654–1661. 1997.
7. Bergh, U., and B. Ekblom. Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiol. Scand.* 107:33–37. 1979.
8. Delecluse, C. Influence of strength training on sprint running performance: 14 current findings and implications for training. *Sports Med.* 24: 147–156. 1997.
9. Doherty, D., D. Robbins, and M. Hodgson. Complex training revisited: A review of its current status as a viable training approach. *Strength Cond. J.* 26(6):52–57. 2004.
10. Duchateau, J., and K. Hainaut. Nonlinear summation of contractions in striated muscle II potentiation of intracellular Ca^{2+} movements in single barnacle muscle fibers. *J. Muscle Res. Cell Motil.* 18–24. 1986.
11. Ebben, W., and P.A. Watts. Review of combined weight training and plyometric modes: Complex training. *J. Strength Cond. Res.* 20:18–27. 1998.
12. Evans, A.K., T.D. Hodkins, M.P. Durcham, J. Berning, and K.J. Adams. The acute effect of a 5 RM bench press on power output (Abstract). *Med. Sci. Sports Exerc.* 32:311. 2000.
13. Fatouros, I., A. Jamourtas, D. Leontisini, K. Taxildaris, G. Agelousis, N. Kostopoulos, and P. Buckenmeyer. Evaluation of plyometric exercise training, weight training and their combination on vertical jumping performance and leg strength. *J. Strength Cond. Res.* 14:470–476. 2000.
14. Gossen, R., and D. Sale. Effect of postactivation potentiation on dynamic knee extension performance. *Eur. J. Appl. Physiol.* 83:524–530. 2000.
15. Gourgoulis, V., N. Aggelousis, P. Kasimatis, G. Mavromatis, and A. Garas. Effect of the submaximal half-squats warm-up program on vertical jumping ability. *J. Strength Cond. Res.* 17:342–344. 2003.
16. Grant, M.D., W.B. Young, and D.A. Aitken. The acute effect of heavy loads on jump squat performance: An evaluation of the complex and contrasting methods of power development. *J. Strength Cond. Res.* 16:530–538. 2002.
17. Gullich, A., and D. Schmidtbleicher. MVC-induced short-term potentiation of explosive force. *New Stud. Athletics* 11:67–81. 1996.
18. Hamada, T., G. Sale, J.D. MacDougall, and M.A. Tarnopolsky. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *J. Appl. Physiol.* 88:2131–2137. 2000.
19. Harris, G.R., M.H. Stone, H.S. O'bryant, C.M. Proulx, and R.L.J. Johnson. Short-term performance effects of high power, high force, or combined weight-training methods. *J. Strength Cond. Res.* 14:14–20. 2000.
20. Hrysomallis, C., and D. Kidgell. Effect of heavy dynamic resistive exercise on acute upper-body power. *J. Strength Cond. Res.* 15:426–430. 2001.
21. Jensen, L.R., and P.W. Ebben. Kinetic analysis of complex training rest interval effect on vertical Jump performance. *J. Strength Cond. Res.* 17: 345–349. 2003.
22. Kotzamanidis, C., D. Chatzopoulos, H. Michailidis, G. Papaiakovou, and D. Patikas. The effect of a combined high resistance training and speed training on the running velocity and jumping ability of soccer players. *J. Strength Cond. Res.* 19:369–375. 2004.
23. Macintosh, B.R., and J.C. Willis. Force-frequency relationship and potentiation in mammalian skeletal muscle. *J. Appl. Physiol.* 88:2088–2096. 2000.
24. McBride, J., S. Nimphius, and T. Erickson. The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance. *J. Strength Cond. Res.* 19:893–897. 2005.
25. Masamoto, N., R. Larson, T. Gates, and A. Faigenbaum. Acute effects of plyometric exercise on maximum squat performance in male athletes. *J. Strength Cond. Res.* 17:68–71. 2003.
26. Mero, A., P.V. Komi, and R.J. Gregor. Biomechanics of sprint running: A review. *Sports Med.* 13:376–392. 1992.
27. Metzger, J.M., M. Greaser, and R.L. Moss. Variations in cross-bridge attachment rate and tension with phosphorylation of myosin in mammalian skinned skeletal muscle fibres. *J. Gen. Physiol.* 93:855–883. 1998.
28. O'brien, B., W. Payne, P. Gastin, and C. Burge. A comparison of active and passive warm ups on energy system contribution and performance in moderate heat. *Aust. J. Sci. Med. Sport* 29:106–109. 1997.
29. Parmigianni, F., and R.B. Stein. Nonlinear summation of contractions in cat muscles: Later facilitation and stiffness changes. *J. Gen. Physiol.* 78:295–311. 1981.
30. Radcliffe, J.C., and J.L. Radcliffe. Effects of different warm-up protocols on peak power output during a single response jump task. *Med. Sci. Sports Exerc.* 28:189. 1996.
31. Rasier, D.E., and B.R. Macintosh. Coexistence of potentiation and fatigue in skeletal muscle. *Braz. J. Med. Biol. Res.* 33:499–508. 2000.
32. Sale, D. Postactivation potentiation: Role in human performance. *Exerc. Sport Sci. Rev.* 30:138–143. 2002.
33. Scott, S., and D. Docherty. Acute effects of heavy preloading on vertical and horizontal jump performance. *J. Strength Cond. Res.* 18:201–205. 2004.
34. Shorten, M.R. Muscle elasticity and human performance. *Med. Sport Sci.* 25:1–18. 1987.
35. Smilios, I., T. Pilianidis, K. Sotiropoulos, M. Antonakis, and S. Tokmakidis. Short-term effects of selected exercise and load in contrast training on vertical jump performance. *J. Strength Cond. Res.* 19:135–139. 2005.
36. Smith, J., C. Fry, W. Weiss, L. Yuhua, and J.K. Stephen. The effects of high-intensity exercise on a 10-second sprint cycle test. *J. Strength Cond. Res.* 15:344–348. 2001.
37. Stewart, D., A. Macaluso, and G. Vito. The effect of an active warm-up on surface EMG and muscle performance in healthy humans. *Eur. J. Appl. Physiol.* 89:509–513. 2003.
38. Trimble, M.H., and S.S. Harp. Post-exercise potentiation of the H-reflex in humans. *Med. Sci. Sports Exerc.* 36:993–941. 1998.
39. Vandervoort, A.A., J. Quinlin, and A.J. McComas. Twitch potentiation after voluntary contraction. *Exp. Neurol.* 81:141–152. 1983.
40. Verkhoshanski, T. Speed strength preparation and development of strength endurance of athletes in various specializations. *Soviet Sports Rev.* 21:120–124. 1973.
41. Young, W., A. Jenner, and K. Griffiths. Acute enhancement of power performance from heavy load squats. *J. Strength Cond. Res.* 12:82–84. 1998.
42. Young, W., B. McLean, and J. Ardagna. Relationship between strength qualities and sprinting performance. *J. Sports Med. Phys. Fitness* 35:13–19. 1995.

Address correspondence to Dr. Kotzamanidis Christos, kotzaman@phed.auth.gr.