

BIOGRAPHICAL SKETCH
Roy E. Ritzmann - Professor

EDUCATION:

B.A., 1969, Zoology, University of Iowa, Iowa City, Iowa

Ph.D., 1974, Biology, University of Virginia, Charlottesville, Virginia

Post-doc., 1974 -77, Neurophysiology, Cornell University, Ithaca, New York

MAJOR RESEARCH INTEREST: Behavioral Neurobiology

EMPLOYMENT:

Postdoctoral Research Assistant in laboratory of J.M. Camhi, 1974 - 1977

NIH Postdoctoral Fellow, 1976 - 1977

Assistant Professor, Department of Biology, Case Western Reserve University (CWRU), Cleveland, Ohio,
1977 - 1983

Associate Professor, Department of Biology, CWRU, Cleveland, Ohio, 1983 - 1992

Adjunct Associate Professor, Department of Neuroscience, CWRU, Cleveland, Ohio, 1989 - 1992

Full Professor, Department of Biology, CWRU, Cleveland, Ohio, 1992 - Present

Adjunct Full Professor, Department of Neuroscience, CWRU, Cleveland, Ohio, 1992 – Present

Director of NSF sponsored IGERT Graduate Training Program in Neuromechanics at CWRU, 1999 - Present

HONORS:

Recipient of NIH Postdoctoral Fellowship, 9/75

Grass Traveling Lecturer, Marshall University, 5/91

Diekhoff award for Graduate Teaching, 5/97

Robot III: Finalist for Discover Magazine's 9th Annual Technology Award, 6/98

Elected Fellow of AAAS, 9/00

Gave Keynote Address at Singapore Robot Olympic Games (with Roger D. Quinn), 5/01

PROFESSIONAL SOCIETIES:

Society for Neurosciences, 1978 - Present

International Society for Neuroethology, 1985 - Present

AAAS, 1989 - Present

Neural Control of Locomotion (by invitation), 1990 - Present

SERVICE TO FUNDING AGENCIES :

Panel Member, NSF Instrumentation and Instrument Development Panel (1988-91)

Panel Member, NSF Undergraduate Laboratory Panel (1991)

NIH Site Visit Team - San Juan, PR. (1992)

Ad hoc reviewer for NSF and USDA

Referee for J. Comp. Physiol, J. Exp. Biol., J. Neurobiol., J. Insect Phys. J. Neurophys.

STUDENTS TRAINED:

Name	Predoc/ Postdoc	Training Period	Grad. Degree	Year	Current Position
<u>Past Graduate Students</u>					
Tobias, M.L.	Pre	78-83	Ph.D.	1983	Sr. Research Sci, Columbia Univ.
Murray, M.P.	Pre	81-87	Ph.D.	1987	Assoc. Prof, Hampshire College
Dieckman, L.J.	Pre	81-85	M.S.	1985	Grad.Student, Univ. of Cincinnati
Nye, S.W.	Pre	88-91	M.S.	1991	Med. Student, Ohio State, Univ.
Casagrand, J.L.	Pre	85-91	Ph.D.	1991	Res. Assoc., Univ. of Colorado
Songhai Chai	Pre	90- 95	Ph.D.	1995	Postdoc. Cleveland State Univ.
Tryba, Andrew	Pre	93-99	Ph.D.	1999	Postdoc. Univ. of Chicago
Dan Greenblatt	Pre	99	M.S.	2000	Medical School – Univ. of Toledo
Paul Schaefer	Pre	93-01	Ph.D.	2001	Medical School – Univ. of Toledo

Past Postdoctoral

James Watson	Post	91- 00	Ph.D.	1989	H.S. Teacher – Cleveland Schools
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Current Post-Graduate Students

Angela Ridgel	Post	01-	Ph.D.	2000	
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Laiyong Mu	Pre	01-	Ph.D.		
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Undergraduate Researchers

Amy Csorba

Sue Hudson

Veruni Kondagunta

Paul Schaefer

Timothy Tufel

David

Gondenswager

J. Mark Saunders

Abel Donka

Ryan Edel

David Mills	1999 - 2000
Rob Kollmorgen	1999 - 2000
Katherine Otto	2000, 2001
Cynthia Rice	2001
Lyndsey Benson	2002

COURSES TAUGHT

Human Physiology

Invertebrate Biology

Neurobiology Laboratory

Neurobiology of Behavior

Organismal Biology

Physiology Laboratory

CURRENT SUPPORT:

ONR Grant N0014-99-1-0378: A Hexapod Robot Based upon Dynamically Scaled Cockroach Mechanics and a Hierarchical, Modular Control Architecture 1/99-12/01.

PI/PD – R.D. Quinn

NSF IGERT Training Grant “Training Program in Neuro-mechanical Systems” 09/99 – 08/04

PI/PD – R.E. Ritzmann

AFOSR “A Climbing Robot for Penetrating Deeply Buried Facilities and Barricaded Positions” 03/01 – 02/03

PI/PD - R.D. Quinn

PUBLICATIONS:

1. Ritzmann, R. (1973) Snapping behavior of the Shrimp *Alpheus californiensis*, *Science* **181**:459-460.
2. Ritzmann, R. E. (1974) Mechanisms for the snapping behavior of two alpheid shrimp, *Alpheus californiensis* and *Alpheus heterochelis*. *J. Comp. Physiol.* **95**:217-236.
3. Ritzmann, R. E., Camhi, J. M. (1978) Excitation of leg motor neurons by giant interneurons in the cockroach *Periplaneta americana*. *J. Comp. Physiol.* **125**:305-316.
4. Ritzmann, R. E., Tobias, M. L., Fournier, C. R. (1980) Flight activity initiated via giant interneurons in the cockroach: Evidence for bifunctional trigger interneurons. *Science* **210**:443-445.
5. Ritzmann, R. E. (1981) Motor responses to paired stimulation of giant interneurons in the cockroach *Periplaneta americana*. II. The ventral giant interneurons. *J. Comp. Physiol.* **143**:61-70.
6. Ritzmann, R. E., Pollack, A. J. (1981) Motor responses to paired stimulation of giant interneurons in the cockroach *Periplaneta americana*. I. The dorsal giant interneurons. *J. Comp. Physiol.* **143**:61-70.
7. Ritzmann, R. E., Pollack, A. J., Tobias, M. L. (1982) Flight activity mediated by intracellular stimulation of dorsal giant interneurons of the cockroach *Periplaneta americana*. *J. Comp. Physiol.* **147**:313-322.
8. Westin, J., Ritzmann, R. E. (1982) The effect of single giant interneuron lesions on wind-evoked motor responses in the cockroach *Periplaneta americana*. *J. Neurobiol.* **13**:127-139.
9. Ritzmann, R. E., Fournier, C. R., Pollack, A. J. (1983) Morphological and physiological identification of motor neurons innervating flight musculature in the cockroach *Periplaneta americana*. *J. Exp. Zool.* **225**:347-356.
10. Tobias, M. L., R. E. Ritzmann (1984) Responses of mesothoracic motor neurons to giant interneuron stimulation in the cockroach. *J. Comp. Physiol.* **154**:633-640.
11. Tobias, M. L., R. E. Ritzmann (1984) Effect of metathoracic leg ablation upon mesothoracic motor responses to giant interneuron stimulation. *J. Comp. Physiol.* **154**:641-647.
12. Ritzmann, R.E., A.J. Pollack (1986) Identification of thoracic interneurons that mediate giant interneuron-to-motor pathways in the cockroach. *J. Comp. Physiol.* **159**:639-654.
13. Simpson, B.S., R. E. Ritzmann, A.J. Pollack (1986) A comparison of the escape behaviors of the cockroaches *Blaberus craniifer* and *Periplaneta americana*. *J. Neurobiol.* **17**:405-415.
14. Dieckman, L.J., R.E. Ritzmann (1987) The effect of temperature on development of flight behavior in the cockroach, *Periplaneta americana*. *J. Neurobiol.* **18**: 487-496.
15. Murrain, M., R.E. Ritzmann (1988) Analysis of proprioceptive inputs to DPG interneurons in the cockroach. *J. Neurobiol.* **19**:552-570.
16. Pollack, A.J., R.E. Ritzmann, J. Westin (1988) Activation of DUM cell interneurons by ventral giant interneurons in the cockroach, *Periplaneta americana*. *J. Neurobiol.* **19**:489-497.
17. Ritzmann, R.E., A.J. Pollack (1988) Wind activated thoracic interneurons of the cockroach: II. Patterns of connection from ventral giant interneurons. *J. Neurobiol.* **19**:589-611.
18. Westin, J., R.E. Ritzmann, D.J. Goddard (1988) Wind activated thoracic interneurons of the cockroach: I. Responses to controlled wind stimulation. *J. Neurobiol.* **19**:573-588.

19. Ritzmann, R.E., A.J. Pollack (1990) Parallel motor pathways from thoracic interneurons of the ventral giant interneuron system of the cockroach, *Periplaneta americana*. *J. Neurobiol.* **21**:1219-1235
20. Casagrand, J.L., R.E. Ritzmann (1991) Localization of ventral giant interneuron connections to VM branch of thoracic interneurons in the cockroach. *J. Neurobiol.* **22**:643-658.
21. Ritzmann, R.E., A.J. Pollack, S.E. Hudson, A. Hyvonen (1991) Convergence of multi-modal sensory signals at thoracic interneurons of the escape system of the cockroach, *Periplaneta americana*. *Brain Res.* **563**:175-183
22. Nye, S.W and R.E. Ritzmann (1992) Motion analysis of leg joints associated with escape turns of the cockroach, *Periplaneta americana*. *J. Comp. Physiol. A* **177**:183-194.
23. Casagrand, J.L. and R.E. Ritzmann (1992) Evidence that synaptic transmission between giant interneurons and identified thoracic interneurons in the cockroach is cholinergic. *J. Neurobiol.* **23**:627-643.
24. Casagrand, J.L. and R.E. Ritzmann (1992) Biogenic amines modulate synaptic transmission between identified giant interneurons and thoracic interneurons in the escape system of the cockroach. *J. Neurobiol.* **23**:644-655.
25. Ritzmann, R.E. and A.J. Pollack (1994) Responses of thoracic interneurons to tactile stimulation in the cockroach, *Periplaneta americana*. *J. Neurobiol.* **25**:1113-1128.
26. Schaefer, P.L., G.V. Kondagunta and R. E. Ritzmann (1994) Motion analysis of escape movements evoked by tactile stimulation in the cockroach, *Periplaneta americana*. *J. exp. Biol.* **190**:287-294.
27. Watson, J.T. and R. E. Ritzmann (1994) The escape response versus the quiescent response of the American cockroach: Behavioural choice mediated by physiological state. *Anim. Behav.* **48**:476-478.
28. Pollack, A.J. , R.E. Ritzmann, J.T. Watson (1995) Dual pathways for tactile sensory information to thoracic interneurons in the cockroach. *J. Neurobiol.* **26**:33-46.
29. Watson, J. T. and R. E. Ritzmann (1995). Combined intracellular stimulation and high speed video motion analysis of motor control neurons in the cockroach. *J. Neurosci. Meth.* **61**:151-157.
30. Beer, R.D., Quinn, R.D., Chiel, H.J., Ritzmann, R.E. (1997) Biologically inspired approaches to robotics: What can we learn from insects? *CACM* **40** (3) 30-38.
31. Chen, C. T., Quinn, R. D., Ritzmann, R.E. (1997) A Crash Avoidance System Based Upon the Cockroach Escape Response Circuit. Proceedings of the 1997 IEEE International Conference on Robotics and Automation (ICRA '97), Albuquerque, NM, April 22-24, 1997.
32. Nelson, G. M., Quinn, R. D., Bachmann, Flannigan, W. C., Ritzmann, R. E., Watson, J. T. (1997) Design and Simulation of a Cockroach-like Hexapod Robot. Proceedings of the 1997 IEEE International Conference on Robotics and Automation (ICRA '97), Albuquerque, NM, April 22-24, 1997.
33. Nelson, G. M., Bachmann, R. J. Quinn, R. D., Watson, J. T., A. K., Tryba, Ritzmann, R. E., "A Cockroach-like Robot," 1998 IEEE International Conference on Robotics and Automation (ICRA '98) Video Proceedings, presented May 1998, Leuven, Belgium.
34. Ritzmann, R.E. and Pollack, A.J. (1998) Characterization of Tactile Sensitive Interneurons in the Abdominal Ganglia of the Cockroach, *Periplaneta americana*. *J. Neurobiol.* **34**:227-241.

35. Watson, J.T. and R.E. Ritzmann (1998) Leg kinematics and muscle activity during treadmill running in the cockroach, *Blaberus discoidalis*: I. Slow running. *J. Comp. Physiol A*. **182**:11-22.
36. Watson, J.T. and R.E. Ritzmann (1998) Leg kinematics and muscle activity during treadmill running in the cockroach, *Blaberus discoidalis*: II. Fast running. *J. Comp. Physiol . A*. **182**:23-33.
37. Beer, R.D., H.J. Chiel, R.D. Quinn and R.E. Ritzmann (1998) Biorobotic Approaches to the Study of Motor Systems. *Cur. Op. Neurobiol.* **8**:777-782.
38. Quinn, R.D. and R.E. Ritzmann (1998) Construction of a Hexapod Robot with Cockroach Kinematics Benefits both Robotics and Biology. *Connection Sci.* **10**: 239-254.
39. Birch, M.C., Quinn, R.D., Hahm, G., Phillips, S., Drennan, B., Fife, A., Verma, H., Beer, R.D., "Design of a cricket microrobot," IEEE Conf. on Robotics and Automation, April 2000, San Francisco, CA.
40. Ritzmann, R.E., R.D. Quinn, J.T. Watson, S.N. Zill (2000) Insect walking and biorobotics: A relationship with mutual benefits. *Bioscience* **50**:23-33.
41. Laksanachoen, S., Pollack, A.J., Nelson, G.M., Quinn, R.D., and Ritzmann, R.E. (2000) Biomechanics and simulation of cricket for microrobot design. *Proc. of the 2000 IEEE Int. Conf. on Robot. and Automat.*, San Francisco.
42. Tryba, A.K. and R.E. Ritzmann (2000) Multi-joint coordination during walking and foothold searching in the *Blaberus* cockroach. I. Kinematics and electromyograms. *J. Neurophysiol.* **83**:3323-3336.
43. Tryba, A.K. and R.E. Ritzmann (2000) Multi-joint coordination during walking and foothold searching in the *Blaberus* cockroach.II. Extensor motor pattern. *J. Neurophysiol.* **83**:3337-3350 .
44. Schaefer, P.L. and R.E. Ritzmann (2001) Descending influences on escape behavior and motor pattern in the cockroach. *J. Neurobiol.* **49**:9-28.
45. Quinn, R.D., Nelson, G.M., Bachmann, R.J., and Ritzmann, R.E. (2001) Toward Mission Capable Legged Robots through Biological Inspiration, *Autonomous Robots*, in press.
46. Kaliyamoorthy, S., Zill, S.N., Quinn, R.D., Ritzmann, R.E., Choi, J. (2001) Finite element analysis of strains in a *Blaberus* cockroach leg during climbing, *Int. Conf. on Intelligent Robots and Systems (IROS)*, Maui, HI, in press.
47. Birch, M.C., Quinn, R.D., Hahm, G., Phillips, S.M., Drennan, B., Fife, A., Beer, R.D., Yu, X., Garverick, S.L., Laksanachoen, S., Pollack, A.J., Ritzmann, R.E., (2001) A Miniature Hybrid Robot Propelled by Legs, *Int. Conf. on Intelligent Robots and Systems (IROS)*, Maui, HI, in press.
48. Vaidyanathan, R., Quinn, R.D., Ritzmann, R.E., Prince, T.S., (2001) *Int. Conf. on Intelligent Robots and Systems (IROS)*, Maui, HI, in press.
49. Quinn, R. D. Nelson, G.M., Bachmann, R.J., Kingsley, D.A., Offi, J. and Ritzmann, R. E. (2001). Insect Designs for Improved Robot Mobility. In *Proc. of Climbing and Walking Robots (CLAWAR) Conference*, Karlsruhe, Germany.
50. Quinn, R.D., Nelson, G.M., Bachmann, R.J., and Ritzmann, R.E. (2001) Toward Mission Capable Legged Robots through Biological Inspiration. *Autonomous Robots*, 11 (3), 215-220.
51. Watson, J.T, Ritzmann, R.E., Zill, S.N. and Pollack, A.J. (2002) Control of Obstacle Climbing in the Cockroach, *Blaberus discoidalis* I. Kinematics. *J.Comp. Physiol. A*. **188**:39-53.

52. Watson, J.T, Ritzmann, R.E., and Pollack, A.J. (2002) Control of Obstacle Climbing in the Cockroach, *Blaberus discoidalis* II. Motor Activities Associated with Joint Movement. *J.Comp. Physiol. A.* **188**:55-69.

ABSTRACTS:

1. Ritzmann, R. E., J. M. Camhi (1976) Responses of leg motor neurons to electrical stimulation of giant axons in the cockroach *Periplaneta americana*. *Soc. Neurosci. Abstr.* **2**:333.
2. Ritzmann, R. E. (1979) Effect of paired stimulation of giant interneurons in the cockroach *Periplaneta americana*. *Soc. Neurosci. Abstr.* **5**:260.
3. Westin, J., Ritzmann, R. E. (1979) Motor output to a cockroach leg in response to wind from different directions. *Soc. Neurosci. Abstr.* **5**:265.
4. Ritzmann, R. E., C. R. Fourtner, M. L. Tobias (1980) Flight activity evoked by intracellular stimulation of giant interneurons in the cockroach *Periplaneta americana*. *Soc. Neurosci. Abstr.* **6**:27.
5. Ritzmann, R. E., C. R. Fourtner, A. J. Pollack (1981) Identification of flight neurons in the cockroach *Periplaneta americana*. *Soc. Neurosci. Abstr.* **7**:410.
6. Tobias, M. L., Ritzmann, R. E. (1982) Motor response of the cockroach mesothoracic ganglion to giant interneuron stimulation. *Soc. Neurosci. Abstr.* **8**:737.
7. Ritzmann, R. E., Pollack, A. J. (1983) Identification of wind sensitive interganglionic interneurons in the cockroach. *Soc. Neurosci. Abstr.* **9**:381.
8. Ritzmann, R. E., Pollack, A. J. (1984) Thoracic interneurons post-synaptic to giant interneurons of the cockroach. *Midwest Neurobiol.*
9. Murrain, M. P., Ritzmann, R. E. (1984) Leg sensory sensitive intersegmental interneurons in the cockroach. *Midwest Neurobiol.*
10. Ritzmann, R. E., Pollack, A. J. (1984) Thoracic interneurons excited by giant interneurons of the cockroach. *Soc. Neurosci. Abstr.* **10**:624.
11. Murrain, M. P., Ritzmann, R. E. (1984) Intersegmental interneurons sensitive to leg sensory structures in the cockroach. *Soc. Neurosci. Abstr.* **10**:625.
12. Simpson, B., Ritzmann, R. E. (1984) A comparison of the escape behavior of the cockroaches *Blaberus craniifer* and *Periplaneta americana*. *Soc. Neurosci. Abstr.* **10**:396.
13. Westin, J., Ritzmann, R. E. (1984) Responses of thoracic interneurons to wind puffs of different directions. *Soc. Neurosci. Abstr.* **10**:625.
14. Pollack, A. J., Ritzmann, R. E. (1985) Morphological and physiological examination of a paired dorsal group of interneurons in the thoracic ganglia of the cockroach. *Soc. Neurosci. Abstr.* **11**:164.
15. Murrain, M., Ritzmann, R. E. (1985) Characterization of thoracic interneurons in the cockroach: physiological and morphological analysis. *Soc. Neurosci. Abstr.* **11**:164.
16. Ritzmann, R. E. (1986) Polysynaptic pathways for escape in the cockroach. *Cong. of Neuroethol. Abstr.* **1**:81.
17. Murrain, M., Ritzmann, R. E. (1986) Characterization of proprioceptive inputs to DPG interneurons in the cockroach. *Soc. Neurosci. Abstr.* **12**:858.

18. Westin, J., Pollack, A. J., Ritzmann, R. E., and Wiblin, R. T (1986) Directional properties of thoracic interneurons in cockroach giant interneuron pathways. *Soc. Neurosci. Abstr.* **12**:858.
19. Pollack, A.J., Ritzmann, R.E. (1987) DUM interneurons are excited by ventral giant interneurons of the cockroach. *Soc. Neurosci. Abst.* **13**:141.
20. Ritzmann, R.E., A.J. Pollack, J. Westin (1987) Integration of directional wind field information in thoracic interneurons of the cockroach. *Soc. Neurosci. Abstr.* **13**:140.
21. Casagrand, J.L., R.E. Ritzmann (1988) Morphological analysis of connectivity between giant interneurons and thoracic interneurons. *Soc. Neurosci. Abstr.* **14**:378.
22. Pollack, A.J., R.E. Ritzmann (1988) Interganglionic motor activation from thoracic interneurons in the vGI system of the cockroach. *Soc. Neurosci. Abstr.* **14**:1000.
23. Westin, J., R.E. Ritzmann (1988) Timing of action potentials in giant interneurons of the cockroach. *Soc. Neurosci. Abstr.* **14**:378.
24. Casagrand, J.L., R.E. Ritzmann (1989) Morphological and developmental analyses of connectivity between giant interneurons and thoracic interneurons. *Midwest Neurobiol.* **12**:18.
25. Casagrand, J.L., R.E. Ritzmann (1989) Connections between ventral giant interneurons and thoracic interneurons of the cockroach occur specifically on the ventral median branch of TIs. *Soc. Neurosci. Abstr.* **15**:1287.
26. Pollack, A.J., R.E. Ritzmann (1989) Thoracic interneurons in the cockroach demonstrate ascending excitation and descending inhibition in patterns of connection. *Midwest Neurobiol.* **12**:13.
27. Pollack, A.J., R.E. Ritzmann (1989) Thoracic interneurons of the ventral giant system excite leg motor neurons of multiple ganglia directly and via local interneurons. *Soc. Neurosci. Abstr.* **15**:1287.
28. Ritzmann, R.E., A.J. Pollack (1989) Motor pathways from thoracic interneurons in the wind mediated escape system of the cockroach. *Cong. of Neuroethol. Abstr.* **2**:24.
29. Beer, R.D., G.J. Kacmarcik, R.E. Ritzmann, H.J. Chiel (1990) A computer model for escape in the cockroach. *Soc. Neurosci. Abstr.* **16**:759.
30. Casagrand, J.L., R.E. Ritzmann (1990) Ventral giant interneuron synapses to thoracic interneurons in the cockroach are chemical and cholinergic. *Soc. Neurosci. Abstr.* **18**:551.
31. Nye, S.W., R.E. Ritzmann (1990) Videotape motion analysis of leg joint angles during escape turns of the cockroach. *Soc. Neurosci. Abstr.* **16**:759.
32. Beer, R.D., G.J. Kacmarcik, S. Chai, R.E. Ritzmann, H.J. Chiel (1991) Ventral giant interneuron wind fields in the cockroach modeled with constrained back-propagation. *Soc. Neurosci. Abstr.* **17**:1245.
33. Casagrand, J.L., R.E. Ritzmann (1991) Biogenic amines modulate synaptic transmission between ventral giant interneurons and thoracic interneurons in the escape system of the cockroach. *Soc. Neurosci. Abstr.* **17**:276.
34. Ritzmann, R.E., A.J. Pollack, S.E. Hudson (1991) Influence of non-giant sensory inputs on the escape response of the cockroach. *Soc. Neurosci. Abstr.* **17**:1245.
35. Pollack, A.J., R.E. Ritzmann (1992) Convergence of antennal and wind inputs on the escape system of the cockroach. *Proc. Int. Cong. Neuroethol.* **3**:251.

36. Watson, J.T. , R.E. Ritzmann (1992) Effects of physiological state on escape behavior and its neural correlates. *Proc. Int. Cong. Neuroethol.* **3**:252.
37. Watson, J.T. , R.E. Ritzmann (1993) Motion analysis of local circuits for the control of leg movements in the cockroach. *Midwest Neurobiol. Meeting* **16**:6.
38. Pollack, A.J. , R.E. Ritzmann (1993) Tactile fields for thoracic interneurons of the escape system of the cockroach. *Soc. Neurosci. Abstr.* **19**:339.
39. Watson, J.T. , R.E. Ritzmann (1993) Analysis of leg movements evoked by intracellular stimulation of neurons in the cockroach. *Soc. Neurosci. Abstr.* **19**:1601.
40. Beer, R.D., W.J. Marx, G.M. Nelson, K.S. Espenschied, R.D. Quinn, J.T. Watson, R.E. Ritzmann, H.J. Chiel. (1994) Contributions of peripheral properties to insect and robot locomotion. *Soc. Neurosci. Abstr.* **20**:1594.
41. Pollack, A.J. , R.E. Ritzmann (1994) Tactile sensory pathways leading to escape circuitry in the cockroach. *Soc. Neurosci. Abstr.* **20**:1594.
42. Watson, J.T. , R.E. Ritzmann (1994) Kinematic and EMG analysis of fast and slow running in the cockroach. *Soc. Neurosci. Abstr.* **20**:777.
43. Pollack, A.J. , R.E. Ritzmann (1995) Tactile interneurons in the abdominal ganglion of the cockroach. *Soc. Neurosci. Abstr.* **21**:409.
44. Watson, J.T. , R.E. Ritzmann (1995) Kinematic analysis of locomotion in the cockroach. *Soc. Neurosci. Abstr.* **21**:427.
45. Chen, C. T., Quinn, R. D., Ritzmann, R. E., "A Crash Avoidance System Based on the Cockroach Escape Response," Proceedings of the Tenth VPI&SU/AIAA Symposium on Dynamics and Control of Large Structures, May 8-10, 1995.
46. Nelson, G.M., R.D. Quinn, J.T. Watson, A.K. Tryba, R.E. Ritzmann, H.J. Chiel, R.D. Beer (1996) Simulated Dynamics of Walking and Climbing in the Cockroach *Soc. Neurosci. Abstr.***22**: 1077.
47. Schaefer, P.L. ,R.E. Ritzmann (1996) Influence of Higher Centers on Thoracic Circuits of the Escape System in Cockroach *Soc. Neurosci. Abstr.***22**: 1143.
48. Watson , J.T. , A.K. Tryba, R.E. Ritzmann (1996) Analysis of Prothoracic Leg Movement During Walking and Climbing in the Cockroach *Soc. Neurosci. Abstr.***22**: 1077.
49. Bachmann, R.J., G.M. Nelson, R.D. Quinn, J.T. Watson, R.E. Ritzmann, (1997) Development of a Cockroach-like Robot for Climbing and Running. *Soc. Neurosci. Abstr.***23**: 767.
50. Schaefer, P.L. , A.J. Pollack, R.E. Ritzmann (1997) Analysis of Descending Influences on Motor Control of Cockroach Escape. *Soc. Neurosci. Abstr.***23**: 1570.
51. Watson , J.T. , A.K. Tryba, R.E. Ritzmann, S.N. Zill. (1997) Coordination of Leg Joints During Complex Locomotion in the Cockroach. *Soc. Neurosci. Abstr.***23**: 767.
52. Bachmann, R. J., Nelson, G. M., Quinn, R. D., Watson, J., Ritzmann, R. E. "Design of a Cockroach-like Robot, Proceedings of the 11th VPI&SU Symposium on Structural Dynamics and Control, May 12-14, 1997.
53. Bachmann, R. J., Nelson, G. M., Quinn, R. D., Watson, J., Tryba, A. K , Ritzmann, R. E. "Construction of a Cockroach-like Hexapod Robot," Sixth IASTED International Conference on Robotics and Automation, Banff, Canada, July 26-29, 1998.

54. Birch, M. C., Quinn, R. D., Zill, S. N., Ritzmann, R. E. (1998) "A Model Cockroach Leg for Sensorimotor Studies," *The Fifth International Congress of Neuroethology*, August 23-28, 1998.
55. Nelson, G. M., Quinn, R. D., Bachmann, R. J., Watson, J. T., Tryba, A. K., Ritzmann, R. E. (1998) Posture Control of a Robot with Cockroach Mechanics, *The Fifth International Congress of Neuroethology*, August 23-28, 1998.
56. Quinn, R. D., Ritzmann, R. E. (1998) A Hexapod Robot based upon Cockroach Mechanics, *The Fifth International Congress of Neuroethology*, August 23-28, 1998.
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5. Ritzmann, R.E. (1989) Seminar at University of Colorado, Boulder, CO.
6. Ritzmann, R.E. (1990) Seminar at Northern Arizona University, Flagstaff, AZ.
7. Ritzmann, R.E. (1991) Seminar at Marshall University, Huntington, WV.
8. Ritzmann, R.E. (1992) Seminar at Duquesne University, Pittsburgh, PA.
9. Ritzmann, R.E. (1992) Seminar at University of Connecticut, Storrs, CO.
10. Ritzmann, R.E. (1993) Seminar at Calvin College, Grand Rapids, Michigan "Control of Orientation and Locomotion Movements in an Insect"
11. Ritzmann, R.E. (1994) Seminar at Ohio State University, Columbus, OH "Control of Orientation and Locomotion Movements in an Insect"
12. Ritzmann, R.E. (1994) Seminar at Columbia University, New York, NY "Control of Orientation and Locomotion Movements in an Insect"
13. Ritzmann, R.E. (1995) Seminar at University of Michigan at Dearborn, Dearborn, MI "Neuroethology: Orientation and Locomotion in Cockroaches, Real and Robotic"
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22. Ritzmann, R.E. (1998) Seminar to “Young Scholars Grand Symposium” at CWRU. "Science-Engineering Interface: Biologically-Inspired Robots" January 17, 1998.
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36. Ritzmann, R.E. (1999) Seminar at University of Tsukuba, Tsukuba - Science City, Japan “Insect Locomotion in Complex Terrain: A Neurobiological and Robotics Approach”, Dec. 3, 1999.

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Featured in television show "Natural Born Robots" on Scientific American Frontiers November 2, 1999

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Participation in Press Conference on "Recovery from Spinal Cord Injury" organized by V.R. Edgerton at Society of Neuroscience Meeting in Miami Beach, FL, October 1999.

Featured in article in *Science* by Gary Taubes. "Biologists and Engineers Create a New Generation of Robots that Imitate Life" *Science* **288**: 80-83

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Research Interest

The Ritzmann laboratory investigates questions that focus on how animals control movement as they negotiate complex terrain. Specifically, we characterize the neural circuits that control leg movements in simple situations like walking on a horizontal treadmill and then investigate how these control circuits modify those movements when they are challenged with more complex situations. The subjects we use for these studies are various species of insects including the cockroaches *Periplaneta americana* and *Blaberus discoidalis* and crickets. In addition to the intrinsic biological value derived from these investigations, data acquired in answering these questions are made available to engineers with whom we maintain an active collaboration for the purposes of designing and constructing biologically inspired robots.

Locomotion System

We have coupled high-speed motion analysis with electrophysiological recordings to understand the neural control of leg movements during locomotion. These data begin to explain how motor activity translates into motion in freely moving animals running on a treadmill. These experiments have tested assumptions that were made based upon observations focusing simply on footfall patterns and EMG activity. Although those data were valuable, they did not factor in the individual roles of each pair of legs that have now been demonstrated by measuring ground reaction forces, as well as the unique ways that each joint moves within each pair of legs. Our data taken in conjunction with observations made by others demonstrate that each pair of legs plays a unique role in locomotion. The hind legs (T_3) act as positive force producing pistons by activating coxa-femur and femur-tibia joints in absolute synchrony. The middle (T_2) legs move these joints in phase but with much smaller movements at the femur-tibia joints. The smaller movements are generated both by activating the extensor muscles with lower frequency activity and as a result of bio-mechanical aspects of the T_2 leg segments. T_2 legs play an important role in rearing the animal up as it climbs over barriers. Front legs (T_1) have variable movements that allow them to reach through an extensive work space. This property makes them particularly well suited for a role as sensori-motor appendages that both move the animal, detect properties of its surroundings and begin the process of climbing over objects.

Current and Future Experiments

We are now extending our observations to animals that are faced with greater challenges. For example, we have begun to study the leg movements associated with actions needed to climb over blocks of various different heights. The animal begins to climb by pitching its body upward by pushing upward with the front and middle legs. The forces that are generated by these legs are re-directed downward. In the case of the middle leg, this requires a postural change associated with movements of the joint between the body and the coxa (initial segment of the leg). Once the animal's body is pitched upward, extension of the hind legs then moves the animal over the barrier. During the climb, the more distal joints of the middle and hind legs move through the same excursions as they do when walking on a horizontal surface, yet the underlying motor activity is much greater for the same joint velocity. The implication is that the animal uses reflex systems during walking to maintain constancy in the movements of these joints even as requirements change according to complex terrains.

Our observations on climbing have led to the notion of varied control strategies. Relatively small barriers seem to be traversed with little active change in leg movements. Rather the dynamics of the animal's body appear to be able to adapt to handle these challenges. With larger barriers, there is a clear change in the movements that make up the climbing strategy. However, detailed analysis indicates that the changes are not as radical as it appears. Rather than being a qualitative change in climbing strategy, there appears to be a few relatively minor postural changes such as the rotation of the middle leg body-coxa joint. These small changes start a cascade of events that quantitatively alter movement in the middle and rear legs. Thus, it

appears that higher neural centers found in head ganglia do not micromanage behavior by switching between control strategies. Rather, having determined that the barrier is too large for simple dynamic alterations, the higher centers dictate a postural adjustment then return control to thoracic circuitry to adjust the strength of movement to the immediate conditions associated with climbing.

The fact that cockroaches place their front legs on top of the barrier accurately with little or no searching behaviors, indicates that they measure the block presumably with sensors mounted on their heads. In particular, antennae seem to be very important. The animals palpate the surface while walking. Upon encountering the block, they rear upward until the antennae can be moved down to an angle of about 140° without touching the top edge of the block. The front legs then swing through movements that are similar to those used in walking to place the tarsus on top of the block.

The role of local control circuits and their interactions with higher centers can only be studied in detail by using intracellular recording techniques. This realization prompted one of our former graduate students, Andrew Tryba, to develop a tethered preparation that allowed him to record from motor neurons and interneurons intracellularly while the animal was making normal walking or searching leg movements. We intend to exploit this preparation for many projects in the future.

The interaction between sensory circuits in higher centers of the nervous system and local circuits in the thoracic ganglia during climbing movements have led to questions about the minimal neural circuitry required for normal walking behavior. Previous reports suggested that most if not all of the neural circuitry necessary for generating walking movements resides in thoracic ganglia. However, when the neck connectives are lesioned, cockroaches do not walk very well at all. This change may be due to the trauma of the surgery. We, therefore, maintained neck lesioned animals alive for several weeks post surgery and found that although the number of steps increased, inter-leg coordination did not return to normal. Neuromodulators can boost the activity level resulting in an order of magnitude more steps. However, again, the animal does not return to a normal tripod gait. Occasional tripod steps do occur, indicating that the circuitry that is necessary for generating that movement is present in the thoracic ganglion, but they are not readily *expressed* in the absence of higher centers.

In contrast to these cervical lesions, cockroaches with lesions further anterior between the suboesophageal ganglion and the brain walk incessantly in a perfect tripod gait. These circumoesophageal lesioned (CoCL) animals do have some deficits. The most obvious is that they do not alter posture in preparation for block climbing. This finding is not surprising, since they do not have access to sensors on their head such as eyes and antennae. However, the reasons for other deficits are less obvious. For example, CoCL animals cannot climb up 45° inclines. Although intact animals have no problem with this task, CoCL's slip and often fall backwards while moving up the incline. This deficit suggests that the brain neuropils have more subtle controls over locomotion on complex terrain than was previously appreciated.

We are currently examining the roles of specific brain regions by coupling smaller brain lesions with high-speed video analysis of turning and climbing. Aluminum foil lances are inserted into specific brain regions, such as the midline neuropils collectively referred to as the central complex. The animals capacity to turn and climb is then compared to video taken on the same animal prior to surgery. Preliminary data suggests that the central complex plays an important role in coordinating leg movements during walking turns. This conclusion is consistent with morphological and behavioral studies made in several other laboratories.

Biologically Inspired Robotic Design

In addition to its intrinsic biological importance, much of the data described above is also used in collaboration with Dr. Roger Quinn's Biorobotics Laboratory in CWRU's Department of Mechanical

Engineering. Two types of vehicles have been designed and constructed. One attempts to follow animal data as closely as possible. The assumption here is that animals have evolved efficient solutions to many of the problems facing robots. Using this philosophy, three very efficient robots have been constructed. We are now working in close collaboration on a series of insect inspired robots (Robots I-V) which are intended to be as cockroach-like as is practical using pneumatic actuators and normal materials. Our kinematic data was used in a simulation tool that was created by one of Dr. Quinn's students. Information gained from this exercise is then used in the design of individual legs. The legs of Robots III through V incorporate the degrees of freedom that we have found are important for both horizontal locomotion and climbing. Dimensions are accurately scaled as are the angles of each leg relative to the body. A postural controller of Robot III allows the robot to stay upright in the face of very serious perturbations and move its body in a remarkably animal-like manner. As we develop the walking and climbing controllers for these robots, the problems that the robotics engineers face tell us much about locomotion in the animal. The information is particularly useful, because the mechanics of these devices were designed so carefully to capture the kinematics of the cockroach.

The other extreme strategy is to use animal studies to solve specific problems facing the robotic design teams. In these cases, the solutions may be abstracted from animal studies rather than mimicking them directly. In a DARPA funded project, Dr. Quinn and we collaborate with several other engineers to develop a small autonomous insect-like robot. The need for autonomy in this vehicle put consider constraints upon power consumption. This problem was accentuated by the small size of the vehicle. As with small animals, small legged vehicles must cycle their legs many more times to go the same distance as a larger vehicle. We, therefore, characterized the walking and jumping movements of the common cricket as inspiration for this vehicle. An interim vehicle was designed and built using the cricket inspired rear legs mounted on a wheeled vehicle.

Another very simple robot that was developed in the Quinn laboratory uses appendages that are hybrid between wheels and legs, which we call "Whlegs". These appendages each have three spokes, but no rim. The result is a longer stance phase than swing for each whleg, even though each Whleg rotates at the same rate. The Whlegs are initially set in an alternating tripod arrangement to generate smooth body movement. However, upon contacting a block, the two legs of each segment mechanically come together to generate a coupled movement similar to that which we have observed in climbing animals. After the climb one leg rotates faster to return to the tripod. All of these movements are purely mechanical. This property along with the fact that all six whlegs rotate at the same rate, allows us to use a single drive motor for the entire robot. The resulting simple robot is remarkably fast and agile.

Conclusion

The investigations that are being carried out in the Ritzmann laboratory provide insight on the neural control of ambulatory behavior. Our strategy in all studies has been to bring a combination of techniques to bear on these problems including high-speed motion analysis of movement, peripheral recording and intracellular recording of identified central neurons. With these tools, we can begin to determine rules by which an animal can assimilate various types of sensory information from both its surroundings and from within its own body and then use that information to control real behavioral movements under real conditions in which its immediate environment as well as the physical forces acting upon its limbs must be taken into consideration. By factoring in real world forces into the equation, we can utilize these data in the design of robotic vehicles that must operate under the constraints of real world forces. Moreover, because our robots are carefully designed to capture the body design and movements of the animal, issues that arise as engineers attempt to control various movements of the robot provide insight into how the animal accomplishes these tasks. Thus, demonstrating the benefits that can be achieved from a close collaboration between engineers and biologists.