List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Sylvia Anton, Angers cedex 01, France
Silvia Arber, Basel, CH
Abdel ElManira, Stockholm, SE
Jan-Marino Ramirez, Seattle, USA
Keith Sillar, St. Andrews, Sco
Hans Straka, LMU, Munich

REVIEWERS NOT TO INCLUDE:

Not Listed

UNIVERSITY OF
LINCOLN

11 June 2019

Dear United States National Science Foundation

I am an authorized representative from the University of Lincoln (UK) and I confirm, on behalf of the University of Lincoln, that the research network between Professor Gregory Sutton (University of Lincoln, UK), Professor Roger Quinn (Case Western Reserve University, USA), Professor Ansgar Büschges (University of Cologne, German), Dr. Jan Ache (University of Würzburg, Germany), Professor Kei Ito (University of Cologne, Germany), Dr. Alexander Blanke (University of Cologne, Germany), Professor Hillel Chiel (Case Western Reserve University, USA), Professor Victoria Webster-Wood (Carnegie Mellon University, USA), Professor Cynthia Chestek (University of Michigan, USA), Professor Martin Fischer (Friedrich-Schiller-Universität, Germany), Professor Alexander Hunt (Portland State University, USA), Professor Marie-Claude Perreault (Emory University, USA), Professor Matthew Tresch (Northwestern University, USA), and Professor CJ Heckman (Northwestern University, USA) is endorsed and has been submitted by University of Lincoln Research Office.

Yours sincerely,

A. Stevenson

Andrew Stevenson
Director, Research and Enterprise
University of Lincoln

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **The individual's Ph.D. advisors; and**
- **All of the individual's Ph.D. thesis advisees.**

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**
- **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
- **Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and**
- **Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.**

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
"Last Active Date" and "Last Active" columns may be left blank for ongoing or current affiliations.

Table 1: List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 r	Last Active Date
	Quinn, Roger, D.	Case Western Reserve University	

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:				

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual's Ph.D. advisors; and

T: All of the individual's Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:	Meirovitch, Leonard	Virginia Tech	

T:	Bachmann, Richard	CWRU	
T:	Birch, Matthew	Remington	
T:	Causey, Gregory	Consultant, Broofield, CO	
T:	Chen, Chun-ta	Taiwan	
T:	Chen, Jiunn		
T:	Choi, Jongung		
T:	Daltorio, Kathryn	CWRU	
T:	Espenschied, Kenneth	Nordson	
T:	Grodsinsky, Carlos	Zin Technologies	
T:	Hunt, Alexander	Portland State	
T:	Jeong, Chan-doo	Samsung	
T:	Kaliyamoorthy, Sathya	Apple	
T:	Kernbaum, Alexander	SRI	
T:	Kernbaum, Nicole	Superflex Technologies	
T:	Kingsley, Daniel	Exponent	
T:	Kolacinski, Richard	Draper Labs	
T:	Laksanacharoen, Sathaporn	Thailand	
T:	Lee, Eunjeong		
T:	Lewinger, William	University of Dundee	
T:	Li, Wei	Private company in China	
T:	Lin, Nan-jou	Taichung, Taiwan	
T:	Mirletz, Brian	Catalia	
T:	Nelson, Gabriel	Boston Dynamics	
T:	Reinhardt, Andrew	Goodyear	
T:	Rutkowski, Adam	Eglin Air Force Base	
T:	Rutter, Brandon	Badgersett Farms	
T:	Sari, Kemal		
T:	Szczecinski, Nicholas	CWRU	
T:	Taylor, Brian	University of North Carolina	
T:	Vaidyanathan, Ravi	Imperial College	
T:	Webster-Wood, Victoria	CMU	
T:	Wei, Terence	Bridgestone	
T:	Xie, Yang		
T:	Yunis, Isam	NASA	

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and

C: Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

4	Name:	Organizational Affiliation	Optional (email, Department) *to disambiguate common names*	Last Active
C:	Akkus, Ozan	CWRU		
C:	Audu, Musa	CWRU		
A:	Bracun, Drago	University of Ljubljana		
A:	Bender, John	General UI Company		

A:	Brown, Amy	Univ. of Illinois		
A:	Büschges, Ansgar	Univ. of Cologne		
A:	Chang, Sarah			
C:	Chiel, Hillel	CWRU		
A:	Diller, Eric	University of Toronto		
A:	Endo, Yoichiro			
C:	Fischer, Martin	University of Jena, Germany		
A:	Gorb, Stanislav	Kiel University, Germany		
A:	Guo, Peiyuan	Vanderbilt		
A:	Harley, Cynthia	University of Minnesota		
A:	Hart, Charles	CMU		
C:	Huang, Helen	North Carolina State		
A:	Hughes, Bradley	National Instruments		
C:	Kobetic, Rudi	Cleveland Veterans Administration		
A:	Kreinar, Edward J.	Setter Research		
C:	Lee, Greg	CWRU		
C:	Martin, Joshua	Colby College		
C:	Merat, Frank	CWRU		
A:	Michaels, Simone	Northrop Grummon Aerospace Systems		
A:	Mu, Laiyong	U of Arizona		
C:	Newman, Wyatt	CWRU		
A:	Palmer, Luther	Wright State Unversity		
A:	Prescott, Tony	Sheffield		
C:	Ritzmann, Roy	CWRU		
C:	Rybak, Ilya	Drexel		
A:	Smith, Lauren	Northrop Grummon Aerospace Systems		
A:	SunSpiral, Vytas	NASA Ames		
C:	Svenson, Gavin	Cleveland Museum of Natural History		
C:	Triolo, Ronald	CWRU		
C:	Tyler, Dustin	CWRU		
C:	Willis, Mark	CWRU		

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

E: Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

			to disambiguate common names	
5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:	Trimmer, Barry	Tufts University	Soft Robotics	
E:				

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
• The individual's Ph.D. advisors; and
• All of the individual's Ph.D. thesis advisees.

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
• Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and
• Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
• Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and
• Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
"Last Active Date" and "Last Active" columns may be left blank for ongoing or current affiliations.

Table 1: List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 r	Last Active Date
	Chiel, Hillel J.	Case Western Reserve University	

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.
R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:	Dreben, Elizabeth K.	Spouse		

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.
G: The individual's Ph.D. advisors; and
T: All of the individual's Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:	Wurtman, Richard J.	M.I.T.	

T:	Douglas Morton		
T:	Sung-Nien Yu		
T:	Hui Ye		
T:	David Neustadter		
T:	Greg Sutton		
T:	Phattanard Phattanasri		
T:	Hui Lu		
T:	Miranda Cullins		
T:	Jeff McManus		
T:	Kendrick Shaw		
T:	Catherine Kehl		
T:	Jeff Gill		
T:	Michael Bending		

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**

C: **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

4	Name:	Organizational Affiliation	Optional (email, Department) *to disambiguate common names*	Last Active
A:	Alexander J. Hunt	Portland State University		
A:	Roger D. Quinn	CWRU		
A:	Kathryn Daltorio	CWRU		
A:	Alexander Lonsberry	CWRU		

A:	Victoria Webster-Wood	CMU		
A:	Peter Thomas	CWRU		
A:	Ozan Akkus	CWRU		
A:	Umut Gurkan	CWRU		
C:	Steven Lewis	CWRU		
A:	Michael Jenkins	CWRU		
C:	Roberto Galan	CWRU		
C:	Marc Buchner	CWRU		
C:	Ilya Rybak	Drexel		
C:	Abraham J. Susswein	Bar Ilan University		
C:	Gregory Sutton	Bristol University		
C:	Charles Horn	Pittsburgh University		
C:	E. Duco Jansen	Vanderbilt University		
C:	Lena Ting	Emory University		
A:	Swarup Bhunia	CWRU		
C:	James Burgess	CWRU		
A:	Orjan Ekeberg	KTH Computer Science and Communication		
A:	Steven Garverick	CWRU		
C:	David Lytte	CWRU		
A:	Heidi Martin	CWRU		
A:	Carlos Mastrangelo	University of Utah		

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

E: Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
E:				

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **The individual's Ph.D. advisors; and**
- **All of the individual's Ph.D. thesis advisees.**

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**
- **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
- **Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and**
- **Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.**

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
“Last Active Date” and “Last Active” columns may be left blank for ongoing or current affiliations.

Table 1: List the individual’s last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 m	Last Active Date
	Heckman, Charles J	Northwestern University	

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:	none			

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual’s Ph.D. advisors; and
T: All of the individual’s Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)

G:	Binder, Marc D	Univerisity of Washington	Physiology and Biophysics
T:	Lee, Robert H	Georgia Tech	Biomedical Engineering
T:	Theiss, Renee D	Governers State University	Physical Therapy
T:	Kuo, Jason	Pharmaceutical Industry	Marketing
T:	Hyngstrom, Allison	Marquette University	Physical Therapy
T:	Kuo, Su-Wei	Duke University	Biomedical Engineering
T:	Schuster, Jenna	Hydrocephalis Foundation	Program Officer
T:	Theeradej Thaweerattanas	National Research Instiute of Thailand	Neuroscience
T:	Huh, Seoan	Abbot Labs	Research Manager, Drug Discovery
T:	Kim, Edward H	Northwestern University	Physiology

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and

C: Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

4	Name:	Organizational Affiliation	Optional (email, Department) *to disambiguate common names*	Last Active
A:	Miller, Laura C.	Northwestern University		4/10/2015
A:	Kim, Hojeong	Daegu Gyeongbuk Institute of Science & Technology		6/18/2015
A:	Sandercock, Thomas G.	Northwestern University		6/18/2015
A:	Collins,III, William F.	Stony Brook University		7/22/2015
A:	Elasiouny, Sherif M.	Wright State University		7/22/2015
A:	DiDonato, Christine J.	Northwestern University		3/7/2016
A:	thaweerattanasinp, Theera	Northwestern University		7/16/2016
A:	Corcos, Daniel M.	Northwestern University		1/1/2017
A:	deMello, Marco Tulio	University of São Paulo		1/1/2017
A:	Forjaz, Claudia	University of São Paulo		1/1/2017
A:	Kanegusuku, Helcio	University of São Paulo		1/1/2017
A:	Piemonte, Maria Elisa Pim	University of São Paulo		1/1/2017
A:	Roschel, Hamilton	University of São Paulo		1/1/2017
A:	Silva-Batista, Carla	University of São Paulo		1/1/2017
A:	Tavares Mattos, Eugenia C	University of São Paulo		1/1/2017
A:	Tricoli, Valmar	University of São Paulo		1/1/2017
A:	Ugrinowitsch, Carlos	University of São Paulo		1/1/2017
A:	Wilson, Jessica M.	Northwestern University		1/1/2017
A:	Che, Le	Jiangxi University of Science and Technology		3/10/2017
A:	Kuo, Su-Wei	Northwestern University		3/10/2017
A:	Yimin, Mao	Northwestern University		3/10/2017
A:	Cain, Charlette	Northwestern University		5/1/2017
A:	Frigon, Alain	Université de Sherbrooke		5/1/2017
A:	Hurteau, Marie-France	Université de Sherbrooke		5/1/2017
A:	Hamm, Thomas M.	St. Joseph's Hospital & Medical Center		7/1/2017
A:	Lee, Robert H.	Georgia Institute of Technoloy		7/1/2017
A:	O'Neill, Derek	St. Joseph's Hospital & Medical Center		7/1/2017
A:	Siripuram, Ramamurthy	Georgia Institute of Technoloy		7/1/2017
A:	V.Turkin, Vladimir	St. Joseph's Hospital & Medical Center		7/1/2017
A:	Seoan, Huh	Northwestern University		7/1/2017
A:	Ciolino, Jody D.	Northwestern University		7/5/2017
A:	Tresch, Matthew C.	Northwestern University		7/5/2017
A:	Klein, D	Northwestern University		9/6/2017
A:	Manuel, Rebecca Imhoff-	Northwestern University		9/6/2017

A:	Tresch, M. C.	Northwestern University		9/6/2017
A:	Tysseling, Vicki M.	Northwestern University		9/6/2017
A:	Chen, Albert	Northwestern University		2/19/2018
A:	Yao, Jun	Northwestern University		2/19/2018
A:	Manuel, Marin	Université Paris Descartes		3/27/2018
A:	Martinez-Silva, Maria De L	Université Paris Descartes		3/27/2018
A:	Roselli, Francesco	Ulm University		3/27/2018
A:	Sharma, Aarti	Columbia University		3/27/2018
A:	Shneider, Neil A	Columbia University		3/27/2018
A:	Zytnicki, Daniel	Université Paris Descartes		3/27/2018
A:	Galonska, Christina	Max Planck Institute for Molecular Genetics		4/5/2018
A:	Gnirke, Andreas	MIT & Harvard		4/5/2018
A:	Gu, Hongcang	MIT & Harvard		4/5/2018
A:	Huang, Mei	Northwestern University		4/5/2018
A:	Kiskinis, Evangelos	Northwestern University		4/5/2018
A:	Maidl, Susanne	Max Planck Institute for Molecular Genetics,		4/5/2018
A:	Martin, Eric J.	Northwestern University		4/5/2018
A:	Meissner, Alexander	MIT & Harvard		4/5/2018
A:	Meltzer, Herbert Y.	Northwestern University		4/5/2018
A:	Ortega, Juan A,	Northwestern University		4/5/2018
A:	Pardo, Alba Di	Northwestern University		4/5/2018
A:	Pop, Ramona	Harvard University		4/5/2018
A:	Quinlan, Katharina A.	University of Rhode Island		4/5/2018
A:	Santos, David P.	Northwestern University		4/5/2018
A:	Ziller, Michael J.	Max Planck Institute for Molecular Genetics,		4/5/2018
A:	Dewald, Julius P. A.	Northwestern University		6/21/2018
A:	Ellis, Michael D.	northwestern University		6/21/2018
A:	Harden, R. Norman	Northwestern University		6/21/2018
A:	McPherson, Jacob G.	Florida International University		6/21/2018
A:	Chow, Jeffrey	Shirley Ryan Ability Lab		7/25/2018
A:	Franz, Colin K.	Northwestern University		7/25/2018
A:	Jordan, Lewis A.	Shirley Ryan Ability Lab		7/25/2018
A:	Ortega, J Alberto	Northwestern University		7/25/2018
A:	Done, Joseph	Northwestern University		11/8/2018
A:	Jiang, Mingchen C.	Northwestern University		11/8/2018
A:	Klumpp, David J.	Northwestern University		11/8/2018
A:	Rosen, John M.	Childrens Mercy		11/8/2018
A:	Rudick, Charles N.	Northwestern University		11/8/2018
A:	schaeffer, Anthony J.	Northwestern University		11/8/2018
A:	Yaggie, Ryan E.	Northwestern University		11/8/2018
A:	Yang, Wenbin	Northwestern University		11/8/2018
A:	Bennett, David J.	University of Alberta		1/1/2019
A:	Hari, Krishnapriya	University of Alberta		1/1/2019
A:	Lin, Shihao	University of Alberta		1/1/2019
A:	Singla, Rahul	Northwestern University		1/1/2019
A:	Stephens, Marilee J.	Northwestern University		1/1/2019
A:	Ying, Zhang	Dalhousie University		1/1/2019
A:	Black, Sophie	University of Alberta		4/23/2019
A:	Fenrich, Keith K.	University of Alberta		4/23/2019
A:	Fouad, Karim	University of Alberta		4/23/2019
A:	Lucas-Osma, Ana M.	University of Alberta		4/23/2019
A:	Murray, Katie	University of Alberta		4/23/2019
A:	Yaqing, Li	Northwestern University		4/23/2019

A:	Farina, Dario	Imperial College London		7/15/2019
A:	Johnson, Michael D.	Northwestern University		7/15/2019
A:	McPherson, Laura M.	Florida International University		7/15/2019
A:	Negro, Francesco	Universita degli Studi Di Brescia		7/15/2019
A:	Powers, Randall K.	University of Washington		7/15/2019
A:	Thompson, Christopher K.	Temple University		7/15/2019
A:	Cox, Gregory A.	The Jackson Laboratory,		3/7/216
A:	Gautam, Mukesh	Northwestern University		3/7/216
A:	Genc, Baris	Northwestern University		3/7/216
A:	Heller, Daniel B	Northwestern University		3/7/216
A:	Jara, Javier H.	Northwestern University		3/7/216
A:	Klessner, Jodi L.	Northwestern University		3/7/216
A:	Ozdinler, P. Hande	Northwestern University		3/7/216
A:	Schultz, Megan C.	Northwestern University		3/7/216
A:	Sekerkova, Gabriella	Northwestern University		3/7/216
A:	Staford, Macdonell J.	Northwestern University		3/7/216
A:	Adimula, Adesoji	Northwestern University		10/24/2017
A:	Ahn, Andrew H.	Teva Pharmaceuticals		4/23/2019

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

E: Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:	William Yates	University of Pittsburgh	Journal of Neurophysiology	6/14/17
E:	Monica Perez	Shirley Ryan AbilityLab	Journal of Neurophysiology	6/14/17

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **The individual's Ph.D. advisors; and**
- **All of the individual's Ph.D. thesis advisees.**

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**
- **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
- **Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and**
- **Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.**

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
“Last Active Date” and “Last Active” columns may be left blank for ongoing or current affiliations.

Table 1: List the individual’s last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12	Last Active Date
	Chestek, Cynthia A.	University of Michigan	Current

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

			to disambiguate common names	
2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:	(None)			

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual’s Ph.D. advisors; and

T: All of the individual’s Ph.D. thesis advisees.

			to disambiguate common names
3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)

G:	Shenoy, Krishna	Stanford University	Electrical Engineering
G:	Henderson, Jaimie	Stanford University	Neurosurgery
T:	David Thompson (postdoc)	Kansas State University	Electrical Engineering
T:	Zachary Irwin	U Alabama Birmingham	Neurosurgery
T:	Karen Schroeder	Columbia U	Neuroscience
T:	Paras Patel	U Michigan	Biomedical Engineering

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**

C: **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

to disambiguate common names

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active
A:	Krishna Shenoy	Stanford University		
A:	Vikash Gilja	U California San Diego		
A:	Paul Nuyujukian	Stanford University		
A:	Euisik Yoon	U of Michigan		
A:	Nicholas Kotov	U of Michigan		
A:	Takashi Kozai	U of Pittsburgh		
A:	Deanna Gates	U of Michigan		
A:	Brian Kelly	U of Michigan		
A:	Jaimie Henderson	Stanford University		
A:	Kim Anderson	Case Western Reserve University		
A:	William Stacey	U of Michigan		
A:	Parag Patil	U of Michigan		
A:	Paul Cederna	U of Michigan		
A:	Adam Sachs	U of Ottawa		
A:	George Mashour	U of Michigan		
A:	Jessica Nicole Bentley	U of Alabama, Birmingham		
A:	Michael Flynn	U of Michigan		
C:	David Blaauw	U of Michigan		
C:	Jamie Philips	U of Michigan		
C:	James Weiland	U of Michigan		
C:	Albert Shih	U of Michigan		
C:	Hunseok Kim	U of Michigan		
C:	Kevin Kilgore	Case Western Reserve University		
C:	Bolu Ajiboye	Case Western Reserve University		
C:	Hunter Peckham	Case Western Reserve University		
C:	Hillel Chiel	Case Western Reserve University		
C:	Roberto Galan	Case Western Reserve University		
C:	Ellis Meng	U of Southern California		
C:	X. Tracy Cui	U of Pittsburgh		
C:	Victoria Wood	Carnegie Mellon University		
C:	Roger Quinn	Case Western Reserve University		

must list the entire editorial board.

B: **Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and**

E: **Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.**

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:	(None)			

E:				

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
• The individual's Ph.D. advisors; and
• All of the individual's Ph.D. thesis advisees.

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
• Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and
• Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
• Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and
• Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
“Last Active Date” and “Last Active” columns may be left blank for ongoing or current affiliations.

Table 1: List the individual’s last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 r	Last Active Date
	Matthew C Tresch	Northwestern University	current
	Matthew C Tresch	Shirley Ryan AbilityLab	current

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual’s Ph.D. advisors; and

T: All of the individual’s Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:	Emilio Bizzi	MIT	

T:	Anthony Jarc	Intuitive Surgical	
T:	Benjamin Rellinger	industry	
T:	Laura Miller	Washington University	
T:	Eric Shearer	Cleveland State University	

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and

C: Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

to disambiguate common names

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active
A:	Cristiano Alessandro	Northwestern University		current
A:	Filipe Barroso	Cajal Institure		current
A:	Benjamin Rellinger	Industry		2018
A:	Vicki Tysseling	Northwestern University		current
A:	Kathy Quinlan	University of Rhode Island		2018
A:	Bryan Yoder	Industry		2018
A:	David Tentler	Northwestern University		current
A:	Josephine Wallner	Northwestern University		current
A:	Amina Kinhabwala	California Institute of Technology		2018
A:	Maria Jantz	University of Pittsburgh		2018
A:	Robert Flint	Northwestern University		current
A:	Ambika Satish	Industry		2018
A:	Sarah Brodnick	University of Wisconsin-Madison		2018
A:	Aaron Suminski	University of Wisconsin-Madison		2018
A:	Justin Williams	University of Wisconsin-Madison		2018
A:	Thomas Sandercock	Northwestern University		current
A:	Yasin Dhaher	University of Texas-Southwestern		2018
A:	Philippe Saltiel	Universite de Montreal		2018
A:	Andrea d'Avella	University of Messina, Santa Lucia Foundation		2018
A:	Kuno Wyler	Industry		2018
A:	David Klein	practicing physician		2018
A:	Rebecca Imhoff-Manuel	Universite de Paris Descartes		2018
A:	Marin Manuel	Universite de Paris Descartes		2018
A:	Elma Kajtaz	Georgia Institutue of Technology		2018
A:	Jody Ciolino	Northwestern University		2018
A:	Raeed Chowdury	University of Pittsburgh		2018
A:	Dinesh Pai	University of British Columbia		2018
A:	Qi Wei	George Mason University		current
A:	Lee E Miller	Northwestern University		current
C:	John Rogers	Northwestern University		current
C:	Philip Gutruf	University of Arizona		current

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

E: Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:	Bill Yates	University of Pittsburgh	Journal of Neurophysiology	current

Not for distribution

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE	☐ Special Exception to Deadline Date Policy	FOR NSF USE ONLY
NSF 19-563 06/14/19		NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) DBI - RESEARCH RESOURCES		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				077758407	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY?
341018992	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
Case Western Reserve University	10900 Euclid Avenue CLEVELAND, OH 441064901 US
AWARDEE ORGANIZATION CODE (IF KNOWN) 0001024000	
NAME OF PRIMARY PLACE OF PERF	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
Case Western Reserve University	Case Western Reserve University 10900 Euclid Avenue Cleveland ,OH ,441064901 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS ☒ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **NeuroNex: Communication, Coordination, and Control in Neuromechanical Systems (C3NS)**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 2	0 months		

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR
☐ DISCLOSURE OF LOBBYING ACTIVITIES
☐ PROPRIETARY & PRIVILEGED INFORMATION
☐ HISTORIC PLACES
☐ VERTEBRATE ANIMALS IACUC App. Date ______
PHS Animal Welfare Assurance Number ______
☒ TYPE OF PROPOSAL Research

☐ HUMAN SUBJECTS Human Subjects Assurance Number ______
Exemption Subsection ______ or IRB App. Date ______
☐ FUNDING OF INT'L BRANCH CAMPUS OF U.S IHE ☐ FUNDING OF FOREIGN ORG
☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED
☒ COLLABORATIVE STATUS
A collaborative proposal from multiple organizations (PAPPG II.D.3.b)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Mechanical & Aerospace Engineering	10900 Euclid Avenue Cleveland,OH 44106 United States
PI/PD FAX NUMBER 216-368-3007	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME Roger D Quinn	PhD	1985	216-368-3222	rdq@po.cwru.edu
CO-PI/PD Cynthia Chestek	PhD	2010	734-707-3356	cchestek@umich.edu
CO-PI/PD Hillel J Chiel	PhD	1980	216-368-3846	hjc@case.edu
CO-PI/PD Charles J Heckman	PhD	1986	312-503-2164	c-heckman@nwu.edu
CO-PI/PD Matthew C Tresch	PhD	1998	312-503-1373	m-tresch@northwestern.edu

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide (PAPPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of PAPPG Chapter IX.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Proposal & Award Policies & Procedures Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Proposal & Award Policies & Procedures Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Proposal & Award Policies & Procedures Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Chapter IX.B. , the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research. The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations.
By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has not been convicted of a felony criminal violation under any Federal law within the 24 months preceding the date on which the certification is signed.

Certification Dual Use Research of Concern

By electronically signing the certification pages, the Authorized Organizational Representative is certifying that the organization will be or is in compliance with all aspects of the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

Foundational question under investigation, rationale for the Network, and anticipated synergies:

Animals move to seek food, mates, and shelter. In the phyla Arthropoda, Mollusca, and Chordata, the nervous system cephalized into a higher-level brain and lower-level sensorimotor network to control behavior. The brain would not exist without a body, and yet surprisingly little is understood about how the nervous system controls and coordinates distributed body parts. Many fundamental questions remain unanswered: How is information encoded and communicated between the more cephalized levels and those dedicated to coordinating multiple body segments? How does the system correct for perturbations from the environment? How does the body's passive biomechanics affect the neuronal response to motion? In sum: **How do biological nervous systems control and execute interactions with the environment?**

We propose an international Network of interdisciplinary research groups (IRGs) consisting of modelers, engineers, and experimentalists to explore the *Communication, Coordination, and Control in Neuromechanical Systems* (**C^{3}NS**). C^{3}NS will investigate the foundational question in model genera from three different phyla: adult *Drosophila* from Arthropoda, adult *Aplysia* from Mollusca, and small mammals from Chordata. Each IRG will study the control of a behavior in which the body interacts with the environment, for example, grasping, feeding, and walking. Investigators will explore how higher-level command centers (HLCCs) formulate descending commands to lower-level motor centers (LLMCs), how systems of subnetworks accomplish the desired behavior in coordination with the animal's biomechanics, and then how they report their status back to HLCCs. Examining this question across different organisms while using the same modeling framework will give rise to a bottom-up theory for how the nervous system controls movement, particularly when interacting with the environment.

Brief description of proposed interdisciplinary research groups (IRGs), including their intellectual merit:

C^{3}NS will contain four IRGs: modelers and experimentalists studying adult *Drosophila* (IRG1), adult *Aplysia* (IRG2), and small mammals (IRG3); and modelers and engineers generalizing the knowledge gained by the other three IRGs (IRG4). All of these model organisms interact strongly with solid media in their environments, as they walk on the ground or grasp and eat food. In addition, each has technical advantages, and current knowledge and models provide foundation for connecting the work. Many genetic tools for network recording and manipulation in behaving animals are available in *Drosophila*, enabling IRG1 to explore individual pathways between the HLCC and LLMC. By applying the MINT NeuroNex Network's carbon fiber electrode (CFE) array, IRG2 will record from many neurons at once as *Aplysia* behaves freely, uncovering the communication protocol between the HLCC and LLMC. Calcium imaging and optogenetic tools will be applied to *Mus* by IRG3 to understand the networks that underlie adaptive behavior in vertebrates. IRG3 will also combine 3D X-ray videography, force plates, and electromyography in *Rattus* to explore the control of perturbed walking. *Felis* offers an even larger nervous system, enabling effective recording from CFE arrays.

Studying animals across three phyla will enable the extraction of general principles of motor control. IRG4 will consolidate the results from IRGs 1-3 to produce an abstracted neuromechanical model that explains the collected data and serves as an embodied theory of motor control. This model will explain how local sensory feedback and biomechanics may simplify the communication needed between the HLCC and LLMC and yet ensure that the body can stably interact with its environment. This neuromechanical model will be implemented both in software and in robots, as a thorough test of its predictions.

Broader impacts such as research, education/outreach, shared facilities and resources, and collaborations:

C^{3}NS will have far reaching broader impacts in biology, health, and robotics. Post-docs and students will be exchanged between laboratories, providing them opportunities to work with different model organisms, leading to better generalization of neuroscience principles, and broadening the trainees' education. Our Network seeks to flip the typical workflow of neuroscience by leveraging our strengths in modeling to build concrete, hypothetical synthetic neural networks to guide experimental research. We will also improve the state of the art in robot control by applying the generalized principles uncovered by this research to develop a method for designing and tuning neural robot controllers.

C^{3}NS will enrich our many existing outreach programs by the presence of international, interdisciplinary collaborators and allow for new, larger initiatives that will reach thousands of people each year. Public demonstrations, day camps and internships will expose K-12 students, primarily from underserved communities, to interdisciplinary research and international collaborators' ideas and culture. We also propose to construct exhibits at natural science museums in our Network's major cities (co-PI Fischer is also a museum director) and an interactive website both describing how very different animals solve similar problems in similar ways with emphasis on how animals control their bodies. Finally, C^{3}NS will present modules at the Interdisciplinary College in Guenne/Moehnesee, Germany.

TABLE OF CONTENTS

For font size and page formatting specifications, see PAPPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

A. Participating Investigators

Roger D. Quinn, Professor, Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland, USA. Theoretical neuromechanical modeling, robotics, IRG1, IRG2, IRG3, IRG4.

Ansgar Büschges, Professor for Animal Physiology and Neurobiology, Department of Biology, Institute of Zoology, Faculty of Mathematics and Natural Sciences, University of Cologne, Germany. Insect neurobiology, IRG1.

Jan M. Ache, Junior Group Leader (starting 10/2019), Department of Neurobiology and Genetics, University of Würzburg, Germany. Insect neurobiology, IRG1.

Kei Ito, Professor for Experimental Morphology and Neuroanatomy, AXA Chair, Department of Biology, Institute of Zoology, Faculty of Mathematics and Natural Sciences, University of Cologne Germany. Insect neurobiology, IRG1.

Alexander Blanke, ERC Research Group Leader, Institute for Zoology, Biocenter, University of Cologne, Germany. Neuromechanical modeling, IRG1, IRG4.

Hillel J. Chiel, Professor, Departments of Biology, Neuroscience, and Biomedical Engineering, Case Western Reserve University, Cleveland, USA. *Aplysia* neurobiology and neuromechanical modeling, IRG2.

Victoria A. Webster-Wood, Assistant Professor, Department of Mechanical Engineering, Department of Biomedical Engineering, Carnegie Mellon University, Pittsburgh, USA. *Aplysia* neuromechanics, robotics, IRG2 and IRG4.

Gregory P. Sutton, Professor, School of Life Sciences, University of Lincoln, Lincoln, UK. Insect and *Aplysia* neuromechanics, IRG2 and IRG4.

Cynthia Chestek, Associate Professor, Biomedical Engineering, University of Michigan, USA. Brain machine interfaces, IRG2.

Martin S. Fischer, Professor, Director of Institute of Systematic Zoology and Evolutionary Biology, Director of Phyletic Museum, Friedrich-Schiller-Universität Jena, Germany. Biomechanics, tetrapod Experimentalist, IRG3.

Alexander J. Hunt, Assistant Professor, Mechanical and Materials Engineering Department, Maseeh College of Engineering and Computer Science, Portland State University, Oregon, USA. Mammalian neuromechanical modeling, robotics, IRG3 and IRG4.

Marie-Claude Perreault, Assistant Professor, Department of Physiology, Faculty of Medicine, Emory University, Atlanta, USA. Neurobiology of mammalian brainstem, IRG3.

Matthew C. Tresch, Professor, McCormick School of Engineering/Physical Medicine and Rehabilitation and Physiology, School of Medicine, Northwestern, USA. Neurobiology of mammalian spinal cord, IRG3.

CJ Heckman, Professor, Associate Chair for Research, Physiology, Physical Medicine & Rehabilitation and Physical Therapy & Human Movement Sciences, Northwestern University Feinberg School of Medicine, Northwestern, USA. Neurobiology of mammalian spinal cord, IRG3.

B. Introduction and Strategic Plan

Rationale, Significance, and Vision of the Network; Need for Synergistic, Interdisciplinary Investigators:

We propose an international Network of interdisciplinary research groups (IRGs) consisting of modelers, engineers, and experimentalists to address the foundational question: **How do biological nervous systems control and execute interactions with the environment?** Animals must solve this problem, whether during walking, grasping, feeding, or other behaviors. Our NeuroNex Network will focus on the *Communication, Coordination, and Control in Neuromechanical Systems* (**C^{3}NS**) to develop a comprehensive model of sensorimotor control and its relationship to the environment, both within individual species, and across the phyla Arthropoda, Mollusca, and Chordata. This comparative analysis of a diversity of organisms is necessary to uncover underlying general principles of sensorimotor control [1]–[3]. The inclusion of modelers and engineers to guide the research of experimentalists will provide a bottom-up, scale-based theory for efficient communication between higher and lower levels of the nervous system. Such a theory will lead to transformative knowledge about how movement is controlled and modulated across the animal kingdom.

The control of behavior is only partially understood for two reasons: the dynamics of downstream networks, and the dynamics of the environment are both extremely complex. First, **the downstream networks that implement motor control are highly dynamic**, containing multiple levels of sensory feedback loops [4], [5], pattern generating networks [3], context-dependent neuromodulation [2], and inter-appendage communication [6]. Such components create a complex context in which the potential simplicity of the descending signals is difficult to understand. For example, when the mollusk *Aplysia californica* feeds, the neuronal networks that control its feeding apparatus naturally generate rhythms to grasp and ingest food in its environment. However, the cerebral ganglion can use ascending sensory information to determine that hard-to-ingest food should be rejected, and this is accomplished by descending commands that alter the phasing of the feeding program. Thus, descending commands may simply modify the phasing of an already-existing program in a dedicated neuronal network, which is economical both in terms of the number of neurons required and the amount of information communicated from the cerebral ganglion to the dedicated neuronal network (buccal ganglion). What is the encoding protocol of these descending commands? What are their exact targets? How does the dynamical nature of these networks affect these commands? We hypothesize that answering these questions will enable us to understand general principles for motor control networks.

Second, **the environment itself is highly dynamic**. For example, as an animal walks through its environment, it must cope with small obstacles, uneven terrain, and other challenges on an instant-to-instant basis. These challenges are solved on multiple levels: passive biomechanics [7]–[9], low-level reflexes, interleg connections [6], and higher-latency ascending pathways to the brain [10], which then forms new descending commands [11]. The higher level command centers make predictions based on past experience, which are updated by ascending information from motor ganglia [12]. What is the protocol used to communicate to the brain the state of the environment as it affects the periphery, and how might reflexes and mechanics simplify these protocols? This is critical to understanding how the brain controls behavior.

Computer and robotic models direct research in three phylum-specific IRGs within our Network, C^{3}NS. Modelers and engineers will generate models whose unknown aspects serve as testable hypotheses related to the foundational question. Experimentalists will evaluate these hypotheses about how each organism executes behaviors within its environment, leading to the refinement of the models. Through IRG4, in which all modelers will participate, common principles and platforms will be developed that will accelerate the work in IRGs 1-3. By understanding sensorimotor integration across three phyla, IRG4 will uncover **general principles** of neuronal communication and coordination.

High-Level Research:

IRG1 will focus on adult *Drosophila melanogaster* (arthropod). To investigate how different neuromeres within the ventral nerve cord (VNC) communicate with one another and higher-level command centers (HLCCs), IRG1 will expand multi-level neuromechanical models of walking, focusing on how ascending and descending signals may modulate the speed and direction of locomotion. The model's hypotheses will be tested by optogenetic techniques that modulate ascending and descending neurons, and by optical and electrophysiological recordings from brain and VNC networks in behaving animals.

IRG2 will focus on adult sea slugs *Aplysia californica* (mollusk). To investigate how biomechanics and sensory feedback simplify communication between HLCCs and lower-level motor centers (LLMCs), IRG2 will develop multi-level neuromechanical models to study behavioral changes implemented by ascending and descending signals. IRG2 will leverage technology developed under MINT, a **previous**

NeuroNex program, to record from many neurons in sea slug ganglia and monitor descending/ascending activity between HLCCs and LLMCs during behavioral changes. Measuring activity from as large a fraction of the nervous system simultaneously is much harder to achieve in insects or mammals. These data will test hypotheses predicted by computer and robotic models, which will serve to refine them.

IRG3 will focus on small mammals (chordates). To investigate how the nervous system coordinates muscle recruitment for different tasks, rejects perturbations while walking, and communicates local and global limb state variables, IRG3 will expand multi-level neuromechanical models of mammalian locomotion. IRG3 will simultaneously record 3D kinematics, 3D dynamics, and electromyography of rats via stereo, high-speed, X-ray camera systems, recording over a dozen muscles' activity during locomotion. Recordings from large populations of neurons in the spinal cord and brainstem during perturbations will elucidate how subsystems throughout the nervous system coordinate to maintain stability. Calcium imaging of neuronal populations in the neonatal mouse will help to elucidate the neuronal networks in the spinal cord and brainstem responsible for such adaptive behavior.

IRG4 will generalize learned principles across phyla. To investigate how body size affects neuronal reactions to perturbations, how feedback loops at different levels of the nervous system minimize perturbations, and how these principles can be exploited to simplify communication between neuronal centers, IRG4 will compare and contrast results and models across IRGs 1-3, and determine common feedback pathways and mechanical forces that transform neuronal activity into controlled behavior. With this knowledge, IRG4 will build a **general model** of multi-level behavioral control. This general model will be validated in both computational and robotic models.

Synergistic Partnerships with Existing Neurotechnology Developments:

C^3NS combines several key neurotechnology and modeling advances from other research fields. IRG1 exploits fly-specific technologies such as optogenetic manipulation and calcium imaging of select neurons in combination with multibody dynamics and finite element analysis based on high-throughput nano-CT scanning, enabling analysis of *Drosophila* neuronal networks, joints, muscles, tissues, and the associated kinematics and kinetics in unprecedented detail on a population wide scale.

IRG2 will track neuronal activity propagation throughout the cerebral and buccal ganglia, and correlate descending and ascending activity, by using the flexible carbon fiber electrode (CFE) array developed by MINT, a previous NeuroNex Network. Recordings of this scale are not practical in other model organisms.

IRG3 will measure many parameters of nominal and perturbed locomotion using stereo, high-speed, X-ray videography coupled to a force plate substrate that enables freely walking rats to have 3D kinematics, 3D dynamics, and electromyography synchronously recorded. IRG3 will also use multi-neuron calcium imaging and CFE array recordings to assess functional connections and recruitment of identified spinal neurons by various descending inputs and to monitor spinal neurons during fictive locomotion, elucidating the networks that underlie intact behavior.

IRG4 will build generalized models of neural control by applying our functional subnetwork approach, which has been shown to readily incorporate neurobiological data into neural models and facilitate their expansion without loss of previous functionality [13], [14]. Some of C^3NS's neurobiologists have found these network models to be sufficiently detailed to compare behavior on a neuron-to-neuron basis [13], [15]. Thus, **this approach is very valuable for framing theories by modeling hypothetical circuits.**

Education:

C^3NS will provide unique opportunities for interdisciplinary education for graduate students and post-docs. The diversity of experimental techniques and organisms is an educational strength of C^3NS as scientists will extend their conceptual horizon in different groups within their IRG, and the Network as a whole. Many of our team members have already established mechanisms for exchanging students. This will be greatly expanded as discussed in Section 4e along with exciting new plans for museum exhibits, an interactive website and other outreach efforts made possible by this Network.

Potential Societal Impacts:

C^3NS's research will have broad impacts in biology, health, and robotics. Exploring the convergent mechanisms of motor control across phyla will lead to a better understanding of the diversity of life on Earth, and may suggest general organizing principles for the nervous system. Understanding the communication protocols between different levels of the nervous system will aid in the investigation of motor disorders that disrupt locomotion and balance, such as Parkinson's, and assist in the development of neurally-controlled prostheses that can effectively process human neural inputs to more naturally and effectively grasp objects or walk smoothly. Control principles may then be applied to robotics, in order to produce machines that more effectively interact with their environment while walking or grasping objects, for example.

C. Interdisciplinary Research Group Descriptions

IRG1 – Studying the sensorimotor transformation between the brain and ventral nerve cord (VNC) in walking, adult Drosophila

To study the origins of adaptive, robust walking in naturalistic environments, IRG1 will study how the adult fruit fly *Drosophila* communicates sensory and motor information between its brain (cerebral and gnathal ganglia) and ventral nerve cord (VNC, thoracic ganglia). The neuronal control of insect locomotion is known to be distributed [3]; the fact that insects are able to walk in the absence of descending connections from brain ganglia underlines this modularity [16]. However, the brain clearly plays an important role in producing adaptive locomotion by processing sensory and ascending information to modulate downstream low level reflexes, modulating inter-ganglion pathways, and initiating, stopping, and modifying locomotion [17]. But many questions remain: What are the types of information shared between the brain and VNC by descending and ascending neurons? What are their neuronal downstream targets? What do these pathways encode? IRG1 will use its neuromechanical modeling method [18], its neurorobot Drosophibot [19], advanced genetic tools, and the experience of the team to experimentally explore these questions synergistically with models and experiments.

This IRG will use computational neuromechanical models of *Drosophila* and the neurorobot, Drosophibot [19], in two roles: Generating hypotheses to test experimentally, and collecting results from multiple levels of the nervous system. First, the neuromechanical model and Drosophibot's neural controller will be expanded based on the IRG's hypotheses, and used as a theoretical framework to guide experimental research. These models will provide targeted hypotheses of what types of neurons and networks may be present in the nervous system, how their activity controls behavior, and how they may be modulated by one another. Second, Drosophibot will provide a substrate for integration across multiple levels of the nervous system, specifically, between the brain and the VNC. As more is learned about a particular part of the network, that part of the model will be validated and updated. As research continues, this model will lead to a more complete, bottom-up theory to explain the descending and ascending control of insect legged locomotion.

Hypothesis 1: Sensory information from the chordotonal organs (CO), campaniform sensilla (CS), hairs (external sensilla, ES), and other sensory organs in the legs is transformed and transmitted in a simple code that is robust to changes in sensor number and placement. The VNC uses this code to share information between neuromeres, and the VNC abstracts this information to communicate with the brain (rather than sending detailed sensory signals).

Hypothesis 2: Descending information from the brain to the VNC regulates walking probability, speed, and direction "indirectly" by acting on pattern generating networks and sensory feedback gains. Similarly, ascending information from the VNC to the brain reports the legs' state via an abstracted code.

Research goals and intellectual focus:

Goal 1: Investigate how neuromeres in the VNC communicate sensory information to one another.

Goal 2: Investigate the types of ascending information sent from the VNC to the brain, how the VNC processes and abstracts this information, and the targets of these pathways.

Goal 3: Investigate the types of descending information sent from the cerebral and gnathal ganglia to the VNC, what networks they target in the VNC, and their context-dependent modulation.

Relationship to the overall Network goals:

Relationship 1: IRG1 will provide data about inter-segmental connections in the VNC and possible communication protocols to IRGs 2 and 3. Such data may suggest communication schemes in their model organisms. Such cross-phylum comparison is necessary to find general principles.

Relationship 2: Results from IRG1 will contribute knowledge about communication protocols between neuromeres to IRG4, in which modelers and engineers will distill general principles regarding ascending/descending control of behavior and use them to build a species-agnostic robotic model of motor control. IRG4 will compare these results to those collected by IRGs 2 and 3.

Planned research activities:

Goal 1: To construct a neuromechanical model to generate concrete hypotheses about control, Quinn and Szczecinski will apply the functional subnetwork approach, which is detailed in IRG4 [18]. Quinn and Szczecinski will expand their previous computational and robotic neuromechanical models of insects, including Drosophibot, to study rhythm generation and motor control in the VNC [20], sensory integration between different segments of the VNC [14], and descending control of motor networks from the brain to the VNC [21], [22]. One strength of this approach is that spiking and nonspiking neurons and synapses can be interfaced and combined, both of which are known to be critical to control motor networks in the VNC [23]. These neural control models will generate concrete models to support Goals 1-3 above.

To understand the communication protocols used within the VNC, Büschges will study sensory encoding schemes, and determine what information is shared between VNC neuromeres to coordinate the legs' timing during walking. Do the neuromeres share raw sensory data, processed sensory data, or abstract leg states with the other legs? Sensory pathways will be monitored via calcium imaging to search for possible sensory encoding schemes, and optogenetically inhibited, to observe the effects of sensory deficits on walking. Transgenic driver lines that label interganglionic connections will be identified. Quinn and Szczecinski will incorporate these findings into their model, and explore how they might simplify the communication between legs. This will extend Büschges' prior work studying insect walking [3], [24], [25], especially interleg coordination of *Drosophila* [26]–[28]. These results will shed light on a more general communication scheme between ganglia, including from the VNC to the brain, intertwining with Goal 2.

The mechanical form of the legs of *Drosophila*, including which degrees of freedom and sensors are present, will be necessary information to understand sensory coding. Blanke, an expert in evolutionary biomechanics [29]–[33], will perform high throughput nano-CT scans of the legs of *Drosophila* from several genetic strains, providing the team with detailed information regarding the placement, number, and orientation of sensors embedded in the exoskeleton (i.e. campaniform sensilla and hairs), as well as the placement and orientation of the degrees of freedom in the leg. This data will enable Büschges to investigate the neuronal basis for robust sensory coding, and will enable Quinn and Szczecinski to construct more detailed anatomical biomechanical models of *Drosophila*.

Goal 2: Transgenic driver lines that target local sensory networks and ascending pathways reveal that sensory information is first transduced and processed in the VNC and sent to the brain via ascending pathways. Ito will leverage his expertise to investigate how the animal is able to monitor its posture, locomotion, and external environment via such pathways. Ito unraveled the first map of ascending pathways in insect nervous systems from the sensory organs in the body to the brain [34], and he will expand this work to find exactly which modalities terminate in the brain, where they terminate [35], how they may be combined or abstracted by the VNC before or while being transmitted, and the latency of such pathways. In addition, Ito will image the activity of these pathways as the animal performs behaviors, such as walking straight, walking along a curve, and starting and stopping walking. These pathways can then be optogenetically activated or suppressed to examine their effect on behavior, specifically, on the fly's ability to overcome perturbations while walking. This work will address Goal 2, but will also contribute to Goal 3.

Goal 3: To understand how sensory cues are encoded in the insect brain and distilled to generate task-dependent descending motor commands, Ache will investigate how descending pathways are affected by behavioral state changes to enable adaptive, context-dependent action selection [36]. Instead of mediating higher-level decision-making processes, Ache will focus on long-distance motor responses to directly connect sensors on the head to motor networks of the VNC, thus enabling rapid behavioral responses [37], [38]. Unravelling the underlying mechanisms will be critical for understanding how locomotor patterns are controlled by sensory signals from the brain. In this project, Ache will combine *in-vivo* electrophysiology and calcium imaging in behaving *Drosophila* to answer three questions: How do descending neurons integrate multimodal sensory and internal state information to enable adaptive locomotion? Is the descending control of locomotion better described by the activity of a few command-like neurons, or by a distributed population code? How is ascending feedback from VNC networks integrated with descending signals to enable adaptive locomotion? These questions are primarily related to Goal 3 above, but will additionally integrate aspects of Goals 1 and 2 to facilitate synergies between the other groups within this IRG.

Achieving interactive, interdisciplinary team-science:

Modelers and experimentalists will work together. This will involve exchanging postdocs and graduate students between labs. For example, Szczecinski will travel to Büschges' and other labs to learn more about experimental techniques, and work side-by-side with staff to develop biologically plausible neural models of their results. In addition, experimental labs will send students to modelers' and engineers' labs, as already happened between Büschges' and Quinn's lab, where experimentalists can learn more about robots and modeling, as well as share detailed information about anatomy with the engineers. We have found that such interdisciplinary exchange enriches both groups, with the experimentalists helping the modelers refine theories and models, and with the modelers generating new, testable hypotheses for experiments [28], [39].

IRG2 – Modeling and measuring signaling between "higher order" and "lower order" ganglia controlling choice and adaptive changes during feeding in the marine mollusk Aplysia californica

The ability to respond rapidly to changing environmental conditions and different mechanical loads is crucial for a variety of behaviors, such as locomotion and grasping. To generalize the understanding of these problems, IRG2 will focus on a flexible form of grasping, feeding behavior in the marine mollusk *Aplysia californica*. IRG2 will determine how interactions between the encephalized cerebral ganglion and the ganglia dedicated to the control of the feeding apparatus (the buccal ganglia) give rise to the ability to adjust, on an instant-to-instant basis, the behavioral choices and forces generated as *Aplysia* consume natural, complex food. In isolation, the buccal ganglia can generate feeding motor programs, but they are primarily egestive patterns; only when connected to the cerebral ganglion can the animal generate flexible ingestive feeding motor patterns [40]. Thus, the "higher level" control due to interneurons within the cerebral ganglion must interact with the "lower level" control in the buccal ganglion to coordinate complex feeding sequences. A great advantage of the *Aplysia* system is that the neurons can be identified reliably across animals, and the large somata are electrically compact, making it possible to regulate all the outputs of the neuron by controlling their activity at the soma. A novel technology developed by MINT, a previous NeuroNex program, carbon fiber electrode (CFE) arrays, makes it possible to selectively control individual neurons while recording from large numbers of neurons. The electrodes are 8 microns in diameter and thus can be inserted through the sheath surrounding the neurons, and record juxta-cellular voltages from individual neurons. The Chiel group has also demonstrated that they can be used to excite or inhibit individual neurons in the ganglion.

A neuromechanical model will integrate and direct the efforts of IRG2. Members of the group will develop a neural model of *Aplysia's* feeding circuitry using the functional subnetwork method (see IRG4) based upon available knowledge about *Aplysia's* nervous system and current understanding of the biomechanics of feeding. To directly connect neuronal activity to behavior and to test the neural model, IRG2 will develop two biomechanical models: a computational model and a novel soft robotic grasper. A computational model can explore a wide range of inputs and parameter values whereas an actual grasper incorporates the physics of the world, providing direct evidence for the effectiveness of the control signals. Previously, investigators in IRG2 developed a grasper based on *Aplysia's* feeding apparatus [41], but it was not fully soft, and it did not completely capture the animal's biomechanics, so this part of the project will also create a novel approach to soft robotic control. The software and robotics models will be controlled by the neural model; predictions of the model will direct animal experiments that will test our hypotheses. *Aplysia* is the one animal in C^{3}NS that will allow us to subsequently control the robot *directly* using neural signals from *Aplysia*. This is valuable because it will provide a direct comparison of animal behavior with the efficacy of the model neural controller.

IRG2 will test two central hypotheses:

Hypothesis 1: Peripheral biomechanics both simplify and constrain the neuronal signals used to choose qualitatively different behaviors, and to modify behavior on an instant-to-instant basis in response to changing environmental conditions.

Hypothesis 2: Behavioral switching or modifications in response to external stimuli are due to a mix of sensory feedback and "higher level" commands.

Research goals and intellectual focus:

Goal 1: Develop neuromechanical models (computational and robotic) of the *Aplysia* feeding system and deduce the key control commands and sensory feedback needed to generate the different biomechanical outputs.

Goal 2: Experimentally test the predictions of the models for both the "lower level" and "higher level" control and communication between the levels for adaptive feeding behavior by measuring and manipulating neurons during behavior, and use the results to refine the neural and biomechanical models.

Goal 3: Compare *in vivo* "higher order" commands with those predicted from the neuromechanical models and from a predictive engineering approach.

Relationship to the overall Network goals:

Relationship 1: Sutton, a member of both IRG2 and IRG4, will provide theory and modeling expertise for slow and fast behaviors dominated by either inertial, viscous or elastic forces.

Relationship 2: Chestek will provide support for signal analysis of higher order neuronal commands for control using predictive machine learning approaches in IRG1 and IRG2.

Relationship 3: Quinn will be a member of all IRGs and will guide the neural modeling effort in the Network using his group's functional subnetwork approach.

Planned research activities:

Goal 1: A model of the neuronal circuits controlling the feeding system will be built using the functional subnetwork approach. The model will be developed by Quinn, Sutton, and Chiel, based on available data about both the neural control and the biomechanics. The model will be used to control the biomechanical models and be refined based upon our experimental results throughout the project. Sutton has created an initial biomechanical model of the feeding apparatus of *Aplysia* that takes firing frequencies as inputs, and predicts forces and movements that can be compared to those of intact animals [42]. Using this model, Sutton will explore ranges of inputs that generate different feeding responses (biting, swallowing or rejection), and predict the variations in the inputs from the motor neurons that can generate each of these behaviors, and how the inputs should vary as the mechanical load increases. His results will be used to refine the neural model. Webster-Wood, who has extensive expertise in developing soft and biohybrid robots, will build on the state-of-the-art in pneumatic actuation [43], [44] and flexible electronics [45] to print novel fiber-reinforced, biomimetic actuators and build a soft robotic grasper based on *Aplysia* feeding apparatus anatomy. She will also explore the inputs that generate biting, swallowing and rejection movements. The neural model will be used to control the robot, and experiments will be conducted to evaluate both models in comparison to the animal's behavior.

Goal 2: Control predictions generated by the computational and hardware neuromechanical models will be tested by Chiel using a preparation that includes the feeding apparatus, the "lower level" buccal ganglion and "upper level" cerebral ganglion [46], recording activity in individual neurons (including sensory neurons) using carbon fiber electrode (CFE) arrays created by the MINT Neuronex Network. These arrays will also be used to manipulate individual neurons (exciting or inhibiting them), and thus the "higher order" commands from the cerebral ganglion and sensory inputs during behavior can be measured, compared to the predictions from the models in Goal 1, and manipulated to test their actual effect on control. Results from this goal directly test Hypothesis 2.

Goal 3: Modern engineering predictive techniques can be used to transform higher order neuronal signals (measured from motor cortex in primates) into control signals for motor control, but often have shortcomings due to the complexity of the primate nervous system. While investigators use a variety of advanced machine learning techniques, essentially all of them maintain a simple linear regression between motor cortex firing rate and endpoint position/velocity, and augment this model with better parameter training [47] or better regularization [48]. How do these techniques compare to the "higher order" signals predicted from the neuromechanical models (Goal 1) or those actually measured in the animal (Goal 2)? Chestek, who is currently using these techniques in studies of finger control in primates, will compare predictive engineering techniques to empirical "ground truth" data in an actual animal to directly test Hypothesis 1, and develop more sophisticated ways of mapping between "higher order" signals and "lower order" signals.

Achieving interactive, interdisciplinary team science:

Twice monthly meetings of all members of IRG2 via Skype will ensure tight integration of theory, modeling and experimental work. Preliminary neuromechanical models (Goal 1) will direct early experimentation by Chiel (Goal 2), which will then refine the models created by Sutton, Quinn, and Webster-Wood in Goal 1, and provide initial inputs to the predictive engineering models generated by Chestek in Goal 3. This will be an iterative process. As data are obtained in Goal 2 and compared to predictions from Goal 1, the models in Goal 1 will be modified to improve their predictive power, which will in turn direct experiments in Goal 2. If neural models that are well-integrated with biomechanics lead to much better control than those generated using advanced machine learning techniques (Goal 3), Chestek will begin to create novel machine learning approaches that integrate biomechanics. Chestek and Webster-Wood will also work together to create a wireless interface [49] that will allow signals from *Aplysia* ganglia to perform *direct, closed loop control* of the novel robotic soft grasper in parallel with direct control of the feeding apparatus to compare the effects of control signals on the mechanical model with the animal's actual behavior. Results will be used to refine the neural and biomechanical models.

Graduate students and postdoctoral fellows will be shared across the different members of IRG2, and regular visits of students to different research groups will be scheduled, so that students will spend time in the different labs of members of IRG2.

Because members of IRG2 will also participate in IRGs 1, 3 and 4, all four IRGs will regularly coordinate their efforts. IRG4 will help to integrate all the different groups by abstracting from the details of each of the models and control architectures used in the three other IRGs to integrate and create general neural control principles.

IRG3 – Studying sensorimotor transformations between spinal and brainstem systems in the mammalian nervous system

IRG3 will study how the state of the body and locomotor commands are encoded and communicated between neuronal systems in the spinal cord and brainstem in mammals. Classic work in cats has established the organization of canonical mammalian spinal circuits, such as the Ia reciprocal inhibitory system Renshaw cells, Ib, and group II neurons [50]. Parallel work has focused on elaborating the organization of pattern generating networks in the spinal cord responsible for locomotion in rodents [51]. Much less is known about the nature of descending systems in the brainstem and how they interact with spinal circuits [52], [53]. More fundamentally, the functional role of these networks remains unclear. How do they interact with one another and with the intelligent mechanics of the musculoskeletal system to enable effective motor control? What sensorimotor control principles do they instantiate? The experiments and analysis of IRG3 will examine these issues, using a combination of behavioral, neurophysiological, and computational experiments and exploiting the range of expertise in our research team. C^3NS will enhance this investigation, with the experiments of IRG3 being strengthened by parallel and complementary experiments in IRGs 1 and 2.

This IRG will use computational neuromechanical models of quadrupedal mammals and the neurorobot Muscle Mutt [54] to play two central roles in this investigation: generating hypotheses and consolidating findings. First, the neural models will be used as a theoretical framework to guide our experimental approach. Hypotheses on the role of spinal circuits will be generated in the model and then evaluated in behavioral and neurophysiological experiments. Second, these models will be used to integrate information obtained from experiments and generate new hypotheses. This iterative loop between theory and experimentation is central to our approach. IRG3 has the following hypotheses:

Hypothesis 1: The spinal cord and brainstem exploit peripheral mechanics to implement a series of hierarchical control strategies that enable the efficient production of effective behavior.

Hypothesis 2: Descending systems in the brainstem exploit the simplification of control produced by spinal circuits such that descending signal commands relate to higher-level behavioral goals.

Research goals and intellectual focus:

Goal 1: To evaluate how mammalian sensorimotor systems maintain robust performance in the face of perturbations due to a continuously changing body and environment.

Goal 2: To evaluate how neurons in the spinal cord and brainstem encode the state of the body in response to changes in the environment.

Goal 3: To evaluate how information about limb state is communicated from the spinal cord to brainstem neurons and how activity in brainstem neurons alters behaviors produced by the spinal cord.

Relationship to the overall Network goals:

Relationship 1: IRG3 will share its results about sensory encoding with IRGs 1 and 2, to suggest possible shared encoding schemes. Such cross-phylum comparison is necessary to discover general principles.

Relationship 2: IRG3 will provide information about the neuronal response to mechanical perturbations to IRG4. Such information will be critical for understanding how nervous systems engage with their environment, including how a robot may walk through or grasp items in its environment.

Planned research activities:

Goal 1: To evaluate how the mammalian nervous system maintains robust locomotion in the face of perturbations, Quinn and Hunt have created neuromechanical computational models and robots to investigate sensorimotor control networks producing locomotion [55]–[57]. These models will be integrated with behavioral experiments by Fischer to characterize the control principles implemented by spinal and brainstem systems. Fischer and Andrada have expertise in comparative biomechanics [58]–[61] and have established techniques to measure synchronously detailed kinematics with biplanar high speed fluoroscopy along with EMGs and force plate recordings during locomotion in small mammals [62], [63]. They have also established sophisticated techniques for dynamically perturbing limbs during locomotion. They will extend these experiments using methods developed in the Tresch lab to record EMG activity chronically in large numbers of muscles across the body.

To evaluate the control strategies implemented by spinal and brainstem systems, Fischer and Andrada will work together with Quinn and Hunt to perform a series of perturbation experiments. They will use both transient perturbations (e.g. torque pulses to limbs, ground displacement) and persistent perturbations (e.g. adding a mass to the torso, changing the incline, or paralyzing a muscle) to evaluate the hypothesis that spinal and brainstem systems regulate higher-level aspects of behavior (e.g. center of mass trajectory, or leg stiffness) while allowing lower-level aspects of movement to vary (e.g. individual joint angles or muscle activation). By examining the latencies of reflexes, they will gain insight into whether responses reflect the actions of spinal or descending circuits. They will use the computational model to design additional perturbations to validate or challenge model assumptions and to test potential theories of control principles implemented by spinal and brainstem circuits. These experiments will also provide critical information to interpret and guide the neurophysiological experiments in Goal 2.

Goal 2: To determine how spinal and brainstem systems encode the state of the limb during transient and persistent perturbations, Heckman will leverage his extensive expertise in the neurophysiological characterization of sensorimotor systems in the spinal cord [64]–[68]. His lab has recently developed techniques for recording simultaneously from large numbers of motoneurons, sensory afferents, and spinal interneurons in response to different perturbations in the cat. He will record from spinal interneurons and brainstem neurons in experiments with the same perturbations used in the experiments of Goal 1. These experiments will identify how local spinal circuits encode information of limb state and communicate this information to the brainstem. Importantly, he will examine this encoding in a functional context, evaluating how neuronal activity in spinal and brainstem systems is related to the control strategies observed in the experiments of Goal 1. These activity patterns will be integrated with the neuromechanical models developed by Hunt and Quinn, evaluating whether they confirm the predictions of the model or suggest refinements.

To improve the possibilities for data collection in spinal systems, Heckman will also work with Tresch to develop similar techniques for recording activity in rats, exploiting the carbon fiber electrode (CFE) arrays developed by the MINT NeuroNex Network. Tresch has expertise in investigating how animals regulate muscle control under perturbations and characterizing spinal neuronal function [69]–[72]. The improved properties of the carbon fiber electrodes will enable these experiments in rats, despite the animal's smaller size. They will compare the activity in spinal and brainstem networks between rats and cats to evaluate whether neuronal circuits are organized differentially across mammals. These experiments in rats will also provide more direct integration with the experiments of Goal 1. Heckman and Tresch will also evaluate the exciting possibility that the properties of these electrodes will permit spinal neuronal recordings in behaving animals. A lack of spinal neuronal activity data in intact animals is a fundamental gap in the understanding of the neural control of movement. Although these would be challenging experiments, they have the potential to transform the field's understanding of motor control.

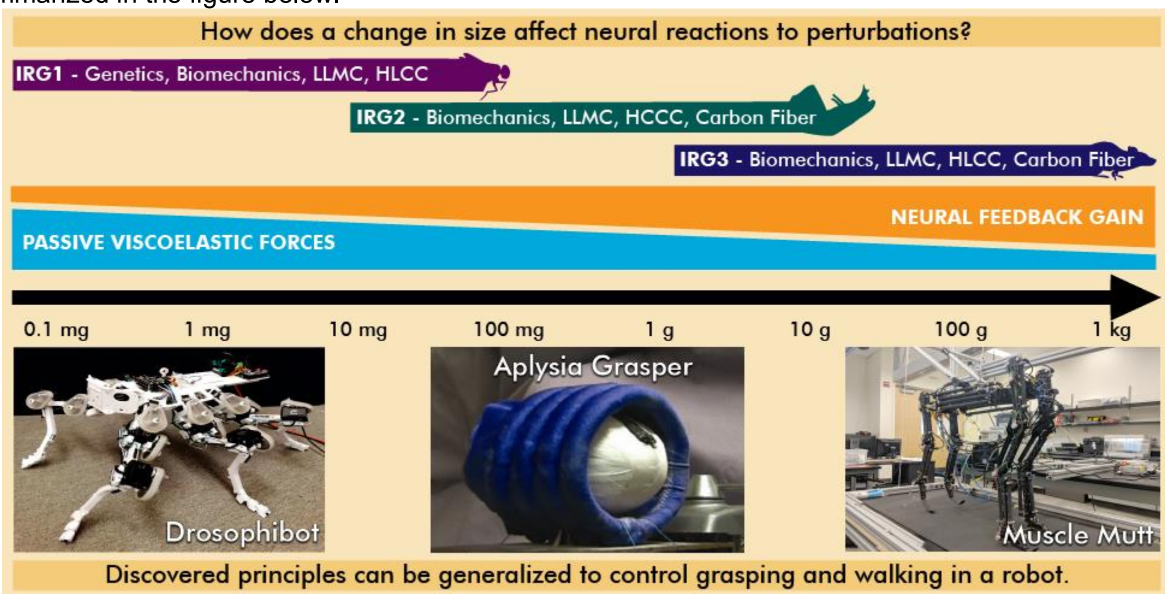
Goal 3: To evaluate how spinal and brainstem systems communicate with one another to produce adaptations of locomotion, Perreault will leverage her extensive expertise examining the function of spinal and brainstem systems in the production and modulation of locomotion [53], [73]–[76]. She will perform experiments to stimulate and inactivate brainstem systems descending to the spinal cord and evaluate their effects on ongoing locomotion. Exploiting the advantages of the *in vitro* mouse spinal cord, Perreault will image activity in functionally distinct populations of identified motoneurons during the production of locomotion. Using electrical stimulation, selective lesions, and optogenetic manipulations, she will investigate how commands from descending brainstem systems alter the timing and amplitude of locomotor outputs. These experiments will also record the activity of spinal interneurons during locomotion and characterize how they are modulated by descending activity. Perreault will also work with Tresch and Heckman to perform complementary experiments *in vivo*, stimulating brainstem sites or descending tracts and evaluating their effect on locomotion and on spinal interneuronal activity. In particular, they will evaluate how descending systems alter activation of motor neurons across the body to modulate key aspects of ongoing movements (e.g. center of mass trajectory, speed or direction of locomotion).

Achieving interactive, interdisciplinary team science in IRG3:

Experimentalists will have several meetings to share techniques as described above. Hunt, Quinn and students in their labs will travel to the labs in Chicago, Jena, and Atlanta to work side-by-side with experimentalists to develop biologically plausible models and to suggest computationally relevant experiments. Similar interactions across all labs in the Network, including regular meetings and visits, will help ensure tight integration between all research efforts.

IRG4 – Consolidating knowledge gained into a species-agnostic model of motor control

IRG4's goal is to build a general model of how higher-level command centers (HLCCs) interface with lower-level motor centers (LLMCs) to perform motions that require interaction with the environment, such as walking or grasping objects. IRG4 consists of modelers from all of the other IRGs. IRG4 will compare and generalize what is uncovered by IRGs 1-3, and explore how mechanics of the animals in question may affect these mechanisms. IRG4 will model and analyze how the dynamical structure of LLMCs and the body itself simplify what information must be shared between the HLCC and LLMC, by considering a series of questions: How does the size of an animal affect its passive mechanics? Does an animal's passive mechanics change the gain or form of feedback necessary for control? How does the combination of these effects simplify the descending control of behavior? The general principles uncovered will be validated by their use in controlling the walking and grasping of a general-purpose robotic platform. These ideas are summarized in the figure below.



Hypothesis 1: There is a fundamental set of reflexes that exist across phyla that stabilize interactions with the environment. These consist of reflexes within the LLMC, as well as motor responses mediated via ascending pathways to the HLCC and descending commands back to the LLMC. The efficacy of such pathways is enhanced by a simple, abstract code for communicating information. The "length," latency, and gain of the pathway are correlated.

Hypothesis 2: The mechanics of the body make a critical contribution to motor control by filtering the mechanical forces generated by the nervous system into controlled motion. The ratio of resistive forces to inertial forces increases as animals become smaller. Small animals evolved a reduction in the gain of negative feedback reflexes as compared to larger animals.

Research goals and intellectual focus:

Goal 1: Understand and model organismal commonalities in how ascending information and descending commands are encoded, transmitted, and decoded by higher and lower level networks.

Goal 2: Extend the continuum of scale down to the fruit fly by incorporating biomechanical data into existing models. Model how the body's passive mechanics filter motor output and how such forces modify the gain of neural feedback pathways.

Goal 3: Construct a set of stabilizing reflexes common to C^{3}NS's model organisms, and use our neuromechanical models to examine how their gain and latency affect each behavior's stability.

Goal 4: Test our generalized model of multi-level motor control in simulation and in robots.

Relationship to the overall Network goals:

Relationship 1: This IRG seeks to generalize the knowledge acquired by IRGs 1-3 into a theoretical framework of the hierarchical control of motion. This includes understanding how information is encoded and transmitted, and how feedback gain and latency scale with organism size and dynamics.

Relationship 2: This IRG will produce generalized neuromechanical models and a real-world robotic implementation of the scale-dependent passive forces and multi-level neural control laws learned from IRGs 1-3. This robot will demonstrate the robustness and stability of the control principles learned in the Network.

Planned research activities:

Goal 1: To construct an initial modeling framework for IRG4, Quinn and Szczecinski will use knowledge gained by IRGs 1-3 and their prior work related to the descending control of locomotion [21], [77], [78] to generalize the form of descending commands needed to modify a given periodic behavior "indirectly" (e.g. modulating phase between different muscles' contractions). Together with Sutton and Hunt, they will explore how processing in the LLMC might abstract sensory information for efficient communication to the HLCC. They will expand their insect-like architectures to include pathways from across phyla, as found both in the literature and from the experiments of IRGs 1-3. This will serve as the groundwork for Goals 2 and 3, which will further explore how local circuits modify these descending commands.

Goal 2: To test theories of how scale affects passive body forces, Blanke will perform high throughput nano-CT scans of the legs of *Drosophila* from several genetic strains, and together with voxel precise material properties, construct multibody dynamics and finite element models to simulate the kinematics, kinetics, and strains present in the legs of freely walking animals. Blanke has expertise in evolutionary biomechanics [29]–[32], with an emphasis on how mechanical form and function relate to one another [33], [79]. Therefore, Blanke will also perform µCT scans of legs from vertebrates in IRG3, and apply the same modeling techniques. Such models will provide insight into the physiological strains present in the leg during a given movement task together with an accurate estimate of the 3D sensory feedback to the HLCC. Sutton, who also has expertise in biomechanics [80], [81], will work with Blanke to translate the quantitative morphology data into mechanical models that approximate the passive forces in the body using material properties. Comparing these measurements across fruit flies, sea slugs, mice, and rats will help clarify how passive forces dynamically scale [8], [82], [83], and is necessary for the models and robots in Goals 3 and 4.

Goal 3: To construct a set of stabilizing reflexes common to C^3NS's model organisms, Hunt will leverage his experience building neuromechanical [57], [84] and neurorobotic [55] models of mammalian locomotion. Hunt has experience applying insect-like pathways to his models in order to fill gaps in the mammalian neuroscience knowledge [57]. Hunt will expand this work with data from IRGs 1-3 to generate a set of intra-limb and inter-limb reflexes necessary to stabilize the posture of an arbitrary body. Sutton will assist this effort by modifying the scaling laws from Goal 2 to predict the strength of active reflexes of larger animals or robots.

Goal 4: To validate the generalized model of the control of interaction with the environment, IRG4 will construct a testbed robot with legs and a flexible grasper. Quinn, Hunt, and Szczecinski will leverage their experience building robotic models of insects [85]–[87], robotic models of mammals [55] and dynamical neural controllers [14], [20]–[22] to construct a species-agnostic legged robot with which to test the general principles extracted by this IRG. They will first construct a dynamic simulation of the robot's mechanics in which the robot's overall scale, the proportions of its leg segments, and the relative orientation of the legs (radial, bilateral, etc.) will be configurable. For each configuration, they will apply the scaled set of generalized passive forces, reflexes, and descending commands in order to control its walking in simulation. One configuration will be selected as the template for a physical robot. Sutton and Webster-Wood will modify the soft robotic grasper from IRG2 to interface with this robot, enabling the robot to interact with the world via several modalities.

IRG4's control models will be successful because of its functional subnetwork approach to constructing neural controllers [18]. This method enables the direct assembly of dynamical neural networks based on observed neuronal activity, as well as quantifying their stability [88]. Quinn, Hunt, and Szczecinski will leverage their experience building neural models and sensory input maps, the gain of reflexes, and the latency of postural control loops (as determined by the work in Goals 1-3) to control the robot. Robot testing will ensure that the generalized principles apply to the real world's physics, noise, and limited communication bandwidth. The hierarchy of control determined in Goal 3 may increase the efficacy of this control system versus the state of the art, because it will not depend on high communication bandwidth.

Achieving interactive, interdisciplinary team-science:

This IRG will achieve interactive team-science because all of its members are experts in mechanics as well as neural systems. This shared background will enable them to frame questions of neural control from a mechanical perspective; the purpose of the nervous system is to control behavior, and without understanding mechanics, the nervous system cannot be understood. This overlap, coupled with otherwise diverse backgrounds, ensures that each investigator will bring a unique perspective to the data collected, contributing to an unbiased, broad generalization of neural and mechanical data from this and other IRGs.

D. Broader Impacts

Contributions to Society:

The research of our Network, C^3NS, will have broad impacts in biology, health, and robotics. C^3NS's exploration of convergent mechanisms of communication between levels of the nervous system and its interaction with the environment across phyla will lead to a better understanding of the diversity of life on Earth, and may suggest general organizing principles for the nervous system.

Understanding the language of communication between different levels of the nervous system will aid in the investigation of motor disorders that disrupt locomotion and grasping, such as Parkinson's. Additionally, it could provide insights into what processes are most affected by aging and injuries, and how we may work to overcome natural deterioration. In addition, it will assist in the development of neurally-controlled prostheses and orthoses that can effectively process descending neuronal signals from the brain, and report sensory feedback to the brain, making these devices easier to use.

Finally, our research will improve the state of the art in robot control by applying the generalized principles uncovered by this research to develop a method for designing and tuning neural controllers for robots. This research will lead to locomotion that is more reliable and robust to perturbations, increasing robots' autonomy and mobility for work in challenging terrains such as on farms, mines, undersea, disaster sites, and other planets. In addition, this research will lead to smarter, biomimetic machines that can more safely and reliably interact with people around them and their environment, increasing their safety.

Education and Training, Human Resource Development, Broadening Participation:

The diversity of experimental techniques and organisms will act as a great educational strength in C^3NS as scientists will extend their research capabilities by learning new techniques utilized by different labs and different IRGs. Additionally, modelers will visit experimental labs and vice versa to learn more about the technical limits of discovery, in order to develop more testable hypotheses. Some of our team members have already established mechanisms for exchanging students. All of these experiences will broaden our trainees' education. PhD students and postdocs will spend at least 1 month per year at host labs within C^3NS and will often travel more often as needed to learn skills and share data and hypotheses.

C^3NS seeks to flip the typical workflow of neuroscience by leveraging our strengths in neuromechanical modeling to build concrete, hypothetical networks to guide experimental research. This translates to exceptional opportunities for interdisciplinary education for undergraduate students, PhD students and post-docs that will greatly broaden their education in diverse ways. Post-docs and students will be exchanged between laboratories within IRGs and within the Network as a whole, providing them opportunities to work with a number of experts in distinct disciplines. They will learn various technologies and different skills. A critical skill that they will master is team work with different personalities in different lab and national cultures. They will learn how to experiment with and model different organisms, leading to better generalization of neuroscience principles.

We expect to train approximately 25 PhD students and postdocs and dozens of undergraduate students. C^3NS will recruit students and postdocs concentrating on broadening participation of minorities and women in science. A number of our PIs have an outstanding record in this endeavor and we expect to improve upon this by consolidating our resources and encouraging our undergraduate students to apply to our Network universities for graduate school.

Outreach Activities, Broadening Participation:

We will expand our many existing outreach programs and enrich them with C^3NS's research and the presence of international, interdisciplinary collaborators. Public demonstrations, day camps and internships will expose primary and secondary (K-12) students, primarily from underserved communities, to interdisciplinary research and international collaborators' ideas and culture.

C^3NS will conduct three new major Network-wide outreach activities that promise to encourage thousands of K-12 students to consider Science, Technology, Engineering, and Mathematics (STEM) in higher education. First, we propose to construct exhibits at science museums in C^3NS's major cities. This is possible because most of the PIs have contacts and previous collaborations with local museums. In fact, Fischer is the Director of the Phyletic Museum in Jena. We will develop an exhibit that will be copied and displayed concurrently at museums in Network cities. The exhibits will include QR-code tags that will lead the visitor to our second major initiative, an interactive website. Third, these exhibits will be shown at the IK [https://www.interdisciplinary-college.de/]. This "interdisciplinary college" fosters education and research between modelers, engineers, and experimentalists. All of these efforts will describe how very different animals solve similar problems in similar ways with emphasis on how animals control behavior.

E. Network Coordination and Management Plan

Specific roles of the collaborating PIs, co-PIs, other Senior Personnel at all participating organizations:

The figure below shows the PIs, co-PIs and other senior personnel in each of the four IRGs. IRGs 1-3 are arranged as columns and are each associated with a particular animal. IRG4 is shown as the orange row on the bottom and includes modelers/engineers from each of the other three IRGs. The pink row indicates that Ache, Ito, Chiel, and Perreault will study head ganglia/midbrain in their particular animal and exchange their findings. The green row indicates that Ache, Ito, Chestek, and Heckman will study ascending/descending signals in their particular animal, and compare their results across phyla. The blue row indicates that Büschges, Blanke, Chiel, Webster-Wood, Fischer, Andrada, and Tresch will study body ganglia/spinal cord. Andrada works with Fischer. Szczecinski works with Quinn and Büschges.

Leadership and organizational structure of the Network:

Each IRG has 5 or 6 co-PIs and will be led by a PI indicated by bold font in the figure. Quinn is the PI of IRG4 and of the entire Network. The organization of each IRG is indicated in the figure. What is not shown in the figure is that we plan to hire a full-time manager who will work with the PIs to organize Network events and meetings, maintain Network data and sharing resources, maintain the Network research website and the interactive learning website, and compile progress reports.

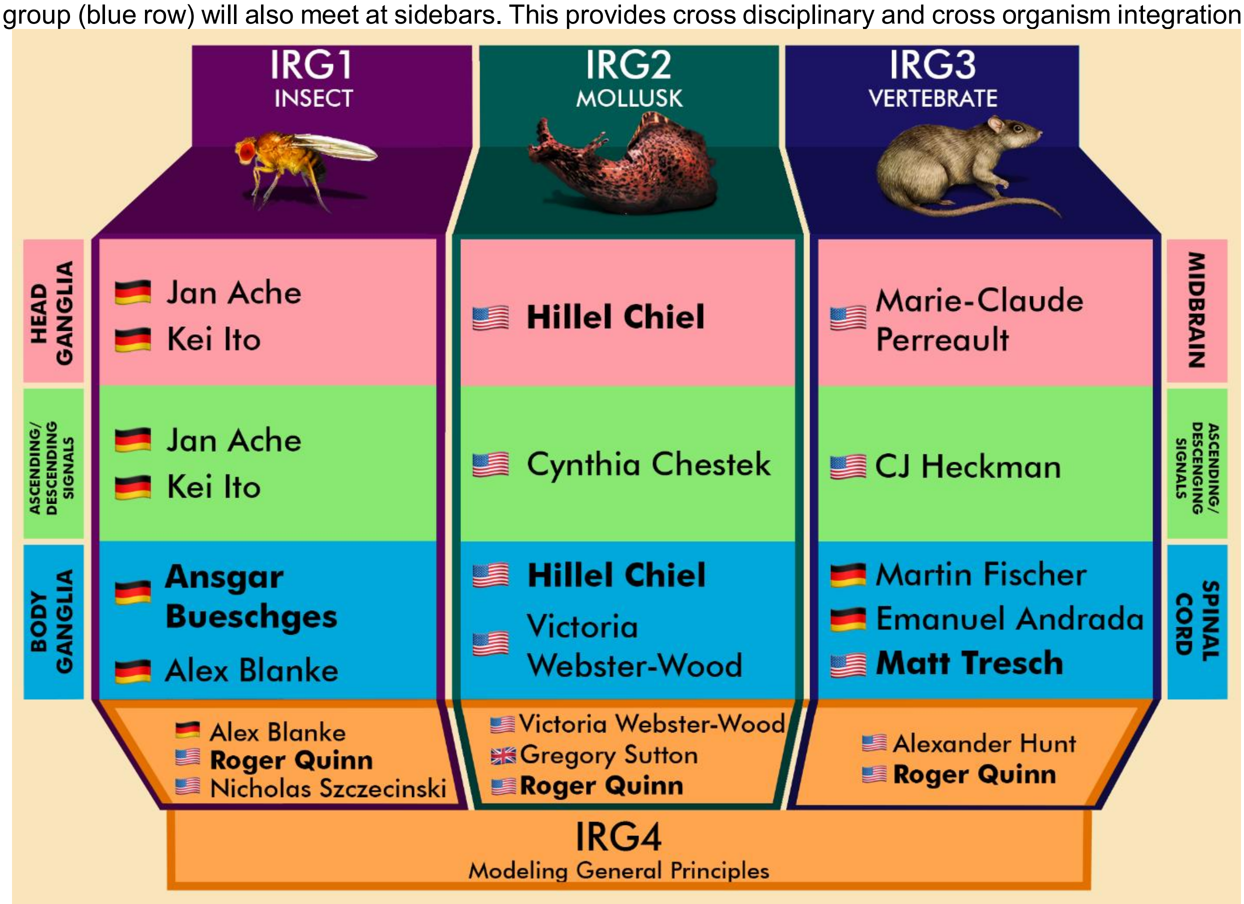
Coordination mechanisms enabling cross-organizational and/or cross-discipline scientific integration:

Organizational: IRG4 consists of the modelers from the other IRGs, which ensures cross IRG integration. Each IRG is interdisciplinary for cross-discipline integration.

Student exchange: Every PhD student and postdoc will spend at least 1 month/year at another lab.

Data sharing: All IRG plans, projects, data, and other documents will be shared through a cloud-based Network website.

Meetings: There will be quarterly meetings of the entire Network: In person meetings twice per year, one during the annual SFN meeting and the other in Europe, and two teleconferences. Each IRG will teleconference twice per month and meet in person during sidebars at the Network meetings. In addition, the head ganglia group (pink row), the inter-level communications group (green row) and the body ganglia group (blue row) will also meet at sidebars. This provides cross disciplinary and cross organism integration.



F. Data and Computing Resource Management Plan

Introduction:

Throughout the duration of the proposed research, data and software will be created and saved as they are generated. Software will consist of synthetic nervous system (SNS) models, neuromechanical models, toolkits for SNS design, and other computational models and optimization strategies. Data will consist of measurements recorded from computational models, animal experiments, and robotic experiments appropriate for each IRG as detailed in the project description. Experimental data will be recorded via data acquisition software with essential metadata present as headers in the relevant electronic files, and video analysis with accompanying charts. Software development and testing will follow common conventions and revision enumeration. These data will be of interest to the computational neuroscience, robotics, autonomous controls, and neurobiology communities. Conference and journal publication information will be submitted to the appropriate repositories at each participating institution for sharing in concert with copyright privileges from the conferences and journals. We will make our software freely available through GitHub, a collaborative software development website, and will develop a public wiki geared towards dissemination to the general public.

IRG and Network Coordination:

To facilitate IRG coordination and communication of results and software between IRGs, a cloud repository will be established through a commercially available platform accessible internationally to all researchers (e.g., Dropbox). Appropriate funds will be requested to support this repository for the duration of the proposed work. The repository will be organized with folders for each IRG and subfolders for each project within the IRGs. Additionally, official versions of software packages developed will be maintained and made available to all IRG members through a controlled GitHub repository to ensure proper version control and revision enumeration.

Data and Software Dissemination:

To support dissemination of research products to the community, C^3NS will maintain a public GitHub repository. Software packages maintained in the private repository will be released to this public repository in a timely manner. Software developed will be easily accessed by researchers and educators in the non-profit sector and available to cooperating commercial entities through contact with the PIs and our website. The terms of software availability will be developed in accordance with local data protection regulations to permit and encourage the dissemination and commercialization of enhanced or customized versions of the software, or incorporation of the software or pieces of it into other computational and robotics systems. The software source code will be transferable such that others can continue to enhance its development. We will take responsibility for creating the original and subsequent official versions of the software. If requested, access to all other data will be provided via contact with the PIs. Data will be available for access and sharing as soon as is reasonably possible. All data dissemination will be performed in accordance with national export control and data protection regulations. We do not anticipate generation of any personally identifiable information (PII) as a result of the proposed research. In the event that PII is generated, such data will not be disseminated publicly and will be stored and processed in accordance with the General Data Protection Regulation (European Union), and the respective Privacy Acts of the USA and Canada. Data will be preserved for at least three years beyond the award period, as required by NSF guidelines.

Local Electronic Data Storage:

In individual laboratories, all local electronic data, and local software copies for backup will be preserved in multiple on-site backups in the form of local RAID arrays and redundant hard drive storage as well as in the cloud repository.

Intellectual Property:

We do not anticipate that there will be any significant intellectual property issues involved with the acquisition of the data. In the event that inventions are made in direct connection with this data, access to the data will be granted upon request once appropriate invention disclosures and/or patent filings are made. The data acquired and preserved in the context of this proposal will be further governed by our universities and national policies pertaining to intellectual property, record retention, and data management.

References

[1] T. Buschmann, A. Ewald, A. Von Twickel, and A. Büschges, “Controlling legs for locomotion - insights from robotics and neurobiology,” *Bioinspiration and Biomimetics*, vol. 10, no. 4, p. 41001, 2015.

[2] A. G. Varga, N. D. Kathman, J. P. Martin, P. Guo, and R. E. Ritzmann, “Spatial Navigation and the Central Complex: Sensory Acquisition, Orientation, and Motor Control,” *Front. Behav. Neurosci.*, vol. 11, no. January, 2017.

[3] S. S. Bidaye, T. Bockemühl, and A. Büschges, “Six-legged walking in insects: how CPGs, peripheral feedback, and descending signals generate coordinated and adaptive motor rhythms,” *J. Neurophysiol.*, 2017.

[4] J. C. Tuthill and R. I. Wilson, “Mechanosensation and Adaptive Motor Control in Insects,” *Curr. Biol.*, vol. 26, no. 20, pp. R1022–R1038, 2016.

[5] A. Mamiya, P. Gurung, and J. C. Tuthill, “Neural Coding of Leg Proprioception in Drosophila,” *Neuron*, vol. 100, no. 3, pp. 636–650, 2018.

[6] V. Dürr, L. M. Theunissen, C. J. Dallmann, T. Hoinville, and J. Schmitz, “Motor flexibility in insects: adaptive coordination of limbs in locomotion and near-range exploration,” *Behav. Ecol. Sociobiol.*, vol. 72, no. 1, 2018.

[7] R. Full and A. Ahn, “Static forces and moments generated in the insect leg: comparison of a three-dimensional musculo-skeletal computer model with experimental measurements,” *J. Exp. Biol.*, vol. 198, no. Pt 6, pp. 1285–98, Jan. 1995.

[8] S. L. Hooper *et al.*, “Neural control of unloaded leg posture and of leg swing in stick insect, cockroach, and mouse differs from that in larger animals.,” *J. Neurosci.*, vol. 29, no. 13, pp. 4109–19, Apr. 2009.

[9] E. Loeb, E. Brown, and J. Cheng, “A hierarchical foundation for models of sensorimotor control,” *Exp. Brain Res.*, pp. 1–18, 1999.

[10] C. L. Chen *et al.*, “Imaging neural activity in the ventral nerve cord of behaving adult Drosophila,” *Nat. Commun.*, vol. 9, no. 1, 2018.

[11] S. J. Kiebel, J. Daunizeau, and K. J. Friston, “A hierarchy of time-scales and the brain,” *PLoS Comput. Biol.*, vol. 4, no. 11, 2008.

[12] R. R. Flanagan, P. Vetter, R. S. Johansson, and D. M. Wolpert, “Prediction precedes control in motor learning,” *Curr. Biol.*, vol. 13, no. 2, pp. 146–150, 2003.

[13] N. S. Szczecinski and R. D. Quinn, “Leg-local neural mechanisms for searching and learning enhance robotic locomotion,” *Biol. Cybern.*, pp. 1–14, 2017.

[14] S. Rubeo, N. Szczecinski, and R. Quinn, “A Synthetic Nervous System Controls a Simulated Cockroach,” *Appl. Sci.*, vol. 8, no. 1, p. 6, 2017.

[15] N. S. Szczecinski, J. P. Martin, D. J. Bertsch, R. E. Ritzmann, and R. D. Quinn, “Neuromechanical model of praying mantis explores the role of descending commands in pre-strike pivots.,” *Bioinspir. Biomim.*, vol. 10, no. 6, pp. 1–18, 2015.

[16] R. E. Ritzmann *et al.*, “Deciding which way to go: How do insects alter movements to negotiate barriers?,” *Front. Neurosci.*, vol. 6, no. JULY, pp. 1–10, 2012.

[17] J. P. Martin, P. Guo, L. Mu, C. M. Harley, and R. E. Ritzmann, “Central-complex control of movement in the freely walking cockroach,” *Curr. Biol.*, vol. 25, no. 21, pp. 2795–2803, 2015.

[18] N. S. Szczecinski, A. J. Hunt, and R. D. Quinn, “A functional subnetwork approach to designing synthetic nervous systems that control legged robot locomotion,” *Front. Neurorobot.*, vol. 11, no. AUG, 2017.

[19] C. Goldsmith, N. Szczecinski, and R. Quinn, “Drosophibot: A Fruit Fly Inspired Bio-Robot,” in *Accepted to Conference on Biomimetic and Biohybrid Systems*, 2019, pp. 1–12.

[20] N. S. Szczecinski, A. E. Brown, J. A. Bender, R. D. Quinn, and R. E. Ritzmann, “A neuromechanical simulation of insect walking and transition to turning of the cockroach Blaberus discoidalis,” *Biol. Cybern.*, vol. 108, no. 1, pp. 1–21, 2014.

[21] N. S. Szczecinski, A. P. Getsy, J. P. Martin, R. E. Ritzmann, and R. D. Quinn, “MantisBot is a Robotic Model of Visually Guided Motion in the Praying Mantis,” *Arthropod Struct. Dev.*, 2017.

[22] S. C. Pickard, R. D. Quinn, and N. S. Szczecinski, “Simulation of the Arthropod Central Complex: Moving Towards Bioinspired Robotic Navigation Control,” in *Biomimetic and Biohybrid Systems*, 2018, pp. 370–381.

[23] E. M. Berg, S. L. Hooper, J. Schmidt, and A. Büschges, “A Leg-Local Neural Mechanism Mediates

the Decision to Search in Stick Insects," *Curr. Biol.*, vol. 25, no. 15, pp. 2012–2017, 2015.
[24] A. Büschges, H. Scholz, and A. El Manira, "New moves in motor control.," *Curr. Biol.*, vol. 21, no. 13, pp. R513-24, Jul. 2011.
[25] A. Borgmann and A. Büschges, "Insect motor control: methodological advances, descending control and inter-leg coordination on the move.," *Curr. Opin. Neurobiol.*, vol. 33C, pp. 8–15, Jan. 2015.
[26] A. Wosnitza, T. Bockemühl, M. Dübbert, H. Scholz, and A. Büschges, "Inter-leg coordination in the control of walking speed in Drosophila," *J. Exp. Biol.*, vol. 216, no. 3, pp. 480–491, 2013.
[27] V. Berendes, S. N. Zill, A. Büschges, and T. Bockemühl, "Speed-dependent interplay between local pattern-generating activity and sensory signals during walking in Drosophila," *J. Exp. Biol.*, no. September, p. jeb.146720, 2016.
[28] N. S. Szczecinski, T. Bockemühl, A. S. Chockley, and A. Büschges, "Static stability predicts the continuum of interleg coordination patterns in Drosophila," *J. Exp. Biol.*, no. October, p. jeb.189142, 2018.
[29] A. Blanke, M. Pinheiro, P. J. Watson, and M. J. Fagan, "A biomechanical analysis of prognathous and orthognathous insect head capsules: evidence for a many-to-one mapping of form to function," *J. Evol. Biol.*, vol. 31, no. 5, pp. 665–674, May 2018.
[30] S. David, J. Funken, W. Potthast, and A. Blanke, "Musculoskeletal modelling of the dragonfly mandible system as an aid to understanding the role of single muscles in an evolutionary context," *J. Exp. Biol.*, vol. 219, no. 7, pp. 1041–1049, 2016.
[31] A. Blanke, P. J. Watson, R. Holbrey, and M. J. Fagan, "Computational biomechanics changes our view on insect head evolution," *Proc. R. Soc. B Biol. Sci.*, vol. 284, no. 1848, 2017.
[32] A. Blanke, "Analysis of modularity and integration suggests evolution of dragonfly wing venation mainly in response to functional demands," *J. R. Soc. Interface*, vol. 15, no. 145, 2018.
[33] A. Blanke, H. Schmitz, A. Patera, H. Dutel, and M. J. Fagan, "Form–function relationships in dragonfly mandibles under an evolutionary perspective," *J. R. Soc. Interface*, vol. 14, no. 128, p. 20161038, Mar. 2017.
[34] K. Ito, T. Yano, T. K. Yokoyama, and A. Tsubouchi, "Understanding neuronal circuits and their functions using expression driver systems of the fruit fly Drosophila melanogaster," in *Neural Coding*, 2016, pp. 26–27.
[35] K. Ito *et al.*, "A systematic nomenclature for the insect brain," *Neuron*, vol. 81, no. 4, pp. 755–765, 2014.
[36] J. M. Ache, S. Namiki, A. Lee, K. Branson, and G. M. Card, "State-dependent decoupling of sensory and motor circuits underlies behavioral flexibility in Drosophila," *Nat. Neurosci.*, 2019.
[37] J. M. Ache, S. S. Haupt, and V. Dürr, "A Direct Descending Pathway Informing Locomotor Networks about Tactile Sensor Movement," *J. Neurosci.*, vol. 35, no. 9, pp. 4081–4091, 2015.
[38] J. M. Ache *et al.*, "Neural Basis for Looming Size and Velocity Encoding in the Drosophila Giant Fiber Escape Pathway," *Curr. Biol.*, vol. 29, no. 6, pp. 1073-1081.e4, 2019.
[39] N. S. Szczecinski, A. Büschges, and T. Bockemühl, "Direction-Specific Footpaths Can Be Predicted by the Motion of a Single Point on the Body of the Fruit Fly Drosophila Melanogaster," in *Conference on Biomimetic and Biohybrid Systems*, 2018, pp. 477–489.
[40] C. C. Horn and I. Kupfermann, "Egestive feeding responses in Aplysia persist after sectioning of the cerebral–buccal connectives: evidence for multiple sites of control of motor programs," *Neurosci. Lett.*, vol. 323, no. 3, pp. 175–178, May 2002.
[41] E. V Mangan, D. A. Kingsley, R. D. Quinn, G. P. Sutton, J. M. Mansour, and H. J. Chiel, "A biologically inspired gripping device," *Ind. Robot An Int. J.*, vol. 32, no. 1, pp. 49–54, Feb. 2005.
[42] V. A. Novakovic, G. P. Sutton, D. M. Neustadter, R. D. Beer, and H. J. Chiel, "Mechanical reconfiguration mediates swallowing and rejection in Aplysia californica," *J. Comp. Physiol. A Neuroethol. Sensory, Neural, Behav. Physiol.*, vol. 192, no. 8, pp. 857–870, 2006.
[43] M. Schaffner, J. A. Faber, L. Pianegonda, P. A. Rühs, F. Coulter, and A. R. Studart, "3D printing of robotic soft actuators with programmable bioinspired architectures," *Nat. Commun.*, vol. 9, no. 1, p. 878, Dec. 2018.
[44] S. Kurumaya, H. Nabae, G. Endo, and K. Suzumori, "Design of thin McKibben muscle and multifilament structure," *Sensors Actuators A Phys.*, vol. 261, pp. 66–74, Jul. 2017.
[45] S. Nagels and W. Deferme, "Fabrication Approaches to Interconnect Based Devices for Stretchable Electronics: A Review," *Materials (Basel).*, vol. 11, no. 3, p. 375, Mar. 2018.
[46] J. M. McManus, H. Lu, and H. J. Chiel, "An In Vitro Preparation for Eliciting and Recording Feeding

Motor Programs with Physiological Movements in Aplysia californica," *J. Vis. Exp.*, no. 70, Dec. 2012.
[47] V. Gilja *et al.*, "A high-performance neural prosthesis enabled by control algorithm design," *Nat. Neurosci.*, vol. 15, no. 12, pp. 1752–1757, Dec. 2012.
[48] J. L. Collinger *et al.*, "High-performance neuroprosthetic control by an individual with tetraplegia," *Lancet*, vol. 381, no. 9866, pp. 557–564, Feb. 2013.
[49] C. A. Chestek, P. Samsukha, M. Tabib-Azar, R. R. Harrison, H. J. Chiel, and S. L. Garverick, "Microcontroller-Based Wireless Recording Unit for Neurodynamic Studies in Saltwater," *IEEE Sens. J.*, vol. 6, no. 5, pp. 1105–1114, Oct. 2006.
[50] E. Jankowska, "Spinal interneuronal networks in the cat: Elementary components," *Brain Res. Rev.*, vol. 57, no. 1, pp. 46–55, 2008.
[51] O. Kiehn, "Development and functional organization of spinal locomotor circuits.," *Curr. Opin. Neurobiol.*, vol. 21, no. 1, pp. 100–9, Mar. 2011.
[52] R. M. Brownstone and J. W. Chopek, "Reticulospinal Systems for Tuning Motor Commands," *Front. Neural Circuits*, vol. 12, no. April, pp. 1–10, 2018.
[53] M. C. Perreault and A. Giorgi, "Diversity of reticulospinal systems in mammals," *Curr. Opin. Physiol.*, vol. 8, pp. 161–169, 2019.
[54] C. Scharzenburger, J. Mendoza, and A. Hunt, "Design of a Canine Inspired Quadruped Robot as a Platform for Synthetic Neural Network Control," in *Accepted to Conference on Biomimetic and Biohybrid Systems*, 2019.
[55] A. Hunt, N. Szczecinski, and R. Quinn, "Development and Training of a Neural Controller for Hind Leg Walking in a Dog Robot," *Front. Neurorobot.*, vol. 11, 2017.
[56] A. J. Hunt, N. S. Szczecinski, E. Andrada, M. S. Fischer, and R. D. Quinn, "Using animal data and neural dynamics to reverse engineer a neuromechanical rat model," in *Biomimetic and Biohybrid Systems*, 2015, vol. 9222, pp. 211–222.
[57] A. J. Hunt, M. Schmidt, M. S. Fischer, and R. D. Quinn, "A biologically based neural system coordinates the joints and legs of a tetrapod," *Bioinspir. Biomim.*, vol. 10, no. 5, p. 055004, 2015.
[58] M. S. Fischer, "Crouched posture and high fulcrum, a principle in the locomotion of small mammals: the example of the rock hyrax (Procavia capensis)(Mammalia: Hyracoidea)," *J. Hum. Evol.*, vol. 26, pp. 501–24, 1994.
[59] M. S. Fischer and R. Blickhan, "The tri-segmented limbs of therian mammals: kinematics, dynamics, and self-stabilization—a review," *J. Exp. Zool. Part A Comp. Exp. Biol.*, vol. 305, no. 11, pp. 935–952, 2006.
[60] R. E. Ritzmann, R. D. Quinn, and M. S. Fischer, "Convergent evolution and locomotion through complex terrain by insects, vertebrates and robots," *Arthropod Struct. Dev.*, vol. 33, no. 3, pp. 361–379, 2004.
[61] J. A. Nyakatura *et al.*, "Reverse-engineering the locomotion of a stem amniote," *Nature*, vol. 565, no. 7739, pp. 351–355, 2019.
[62] M. S. Fischer, "Kinematics, EMG, and inverse dynamics of the therian forelimb-a synthetic approach," *Zool. Anz.*, vol. 238, no. 1, pp. 41–54, 1999.
[63] E. Andrada, L. Reinhardt, K. Lucas, and M. S. Fischer, "Three-dimensional inverse dynamics of the forelimb of beagles at a walk and trot," *Am. J. Vet. Res.*, vol. 78, no. 7, pp. 804–817, 2017.
[64] R. H. Lee and C. J. Heckman, "Bistability in Spinal Motoneurons In Vivo: Systematic Variations in Persistent Inward Currents," *J. Neurophysiol.*, vol. 80, no. 2, pp. 583–593, 2017.
[65] C. J. Heckman, M. A. Gorassini, and D. J. Bennett, "Persistent inward currents in motoneuron dendrites: Implications for motor output," *Muscle and Nerve*, vol. 31, no. 2, pp. 135–156, 2005.
[66] C. J. Heckman and R. M. Enoka, "Motor Unit," in *Comprehensive Physiology*, Hoboken, NJ, USA: John Wiley & Sons, Inc., 2012.
[67] C. K. Thompson *et al.*, "Robust and accurate decoding of motoneuron behaviour and prediction of the resulting force output," *J. Physiol.*, vol. 596, no. 14, pp. 2643–2659, 2018.
[68] M. Manuel, M. Chardon, V. Tysseling, and C. J. Heckman, "Scaling of Motor Output, From Mouse to Humans," *Physiology*, vol. 34, no. 1, pp. 5–13, 2018.
[69] M. Berniker, A. Jarc, E. Bizzi, and M. C. Tresch, "Simplified and effective motor control based on muscle synergies to exploit musculoskeletal dynamics.," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 106, no. 18, pp. 7601–6, May 2009.
[70] M. C. Tresch and A. Jarc, "The case for and against muscle synergies," *Curr. Opin. Neurobiol.*, vol.

19, no. 6, pp. 601–607, 2009.
[71] R. H. Chowdhury, M. C. Tresch, and L. E. Miller, “Musculoskeletal geometry accounts for apparent extrinsic representation of paw position in dorsal spinocerebellar tract,” *J. Neurophysiol.*, vol. 118, no. 1, pp. 234–242, 2017.
[72] C. Alessandro, B. A. Rellinger, F. O. Barroso, and M. C. Tresch, “Adaptation after vastus lateralis denervation in rats demonstrates neural regulation of joint stresses and strains,” *Elife*, vol. 7, pp. 1–18, 2018.
[73] M. C. Perreault, T. Drew, and S. Rossignol, “Activity of medullary reticulospinal neurons during fictive locomotion,” *J. Neurophysiol.*, vol. 69, no. 6, pp. 2232–2247, 2017.
[74] C. Jean-Xavier and M. C. Perreault, “Influence of brain stem on axial and hindlimb spinal locomotor rhythm generating circuits of the neonatal mouse,” *Front. Neurosci.*, vol. 12, no. FEB, pp. 1–14, 2018.
[75] M. S. Sivertsen, M. C. Perreault, and J. C. Glover, “Pontine reticulospinal projections in the neonatal mouse: Internal organization and axon trajectories,” *J. Comp. Neurol.*, vol. 524, no. 6, pp. 1270–1291, 2016.
[76] N. Kasumacic *et al.*, “Segmental Organization of Vestibulospinal Inputs to Spinal Interneurons Mediating Crossed Activation of Thoracolumbar Motoneurons in the Neonatal Mouse,” *J. Neurosci.*, vol. 35, no. 21, pp. 8158–8169, 2015.
[77] N. S. Szczecinski and R. D. Quinn, “MantisBot Changes Stepping Speed by Entraining CPGs to Positive Velocity Feedback,” in *Lecture Notes in Artificial Intelligence 10384*, 2017, pp. 440–52.
[78] N. S. Szczecinski and R. D. Quinn, “Template for the Neural Control of Directed Walking Generalized to All Legs of MantisBot,” *Bioinspiration and Biomimetics*, 2017.
[79] S. David, J. Funken, W. Potthast, and A. Blanke, “Musculoskeletal modelling under an evolutionary perspective: Deciphering the role of single muscle regions in closely related insects,” *J. R. Soc. Interface*, vol. 13, no. 123, 2016.
[80] M. Burrows and G. Sutton, “Interacting Gears Synchronize Propulsive Leg Movements in a Jumping Insect,” *Science (80-.).*, vol. 341, no. 6151, pp. 1254–1256, Sep. 2013.
[81] M. Burrows, D. A. Cullen, M. Dorosenko, and G. P. Sutton, “Mantises exchange angular momentum between three rotating body parts to jump precisely to targets,” *Curr. Biol.*, vol. 25, no. 6, pp. 786–789, 2015.
[82] M. Ilton *et al.*, “The principles of cascading power limits in small, fast biological and engineered systems,” *Science (80-.).*, vol. 360, no. 6387, 2018.
[83] M. S. Garcia, A. D. Kuo, A. Peattie, P. Wang, and R. J. Full, “Damping And Size: Insights And Biological Inspiration,” *Int. Symp. Adapt. Motion Anim. Mach.*, pp. 1–7, 2000.
[84] K. Deng *et al.*, “Neuromechanical Model of Rat Hindlimb Walking with Two-Layer CPGs,” *Biomimetics*, vol. 4, no. 1, p. 21, 2019.
[85] K. S. Espenschied, R. D. Quinn, R. D. Beer, and H. J. Chiel, “Biologically based distributed control and local reflexes improve rough terrain locomotion in a hexapod robot,” *Rob. Auton. Syst.*, vol. 18, no. 1–2, pp. 59–64, Jul. 1996.
[86] G. M. Nelson, R. D. Quinn, R. J. Bachmann, W. C. Flannigan, R. E. Ritzmann, and J. T. Watson, “Design and simulation of a cockroach-like hexapod robot,” *Proc. Int. Conf. Robot. Autom.*, vol. 2, no. April, pp. 3–8, 1997.
[87] N. S. Szczecinski *et al.*, “Introducing MantisBot: Hexapod robot controlled by a high-fidelity, real-time neural simulation,” in *IEEE International Conference on Intelligent Robots and Systems*, 2015, pp. 3875–3881.
[88] N. S. Szczecinski, A. J. Hunt, and R. D. Quinn, “Design process and tools for dynamic neuromechanical models and robot controllers,” *Biol. Cybern.*, vol. 111, no. 1, 2017.

BIOGRAPHICAL SKETCH

Roger D. Quinn, PhD
Arthur P. Armington Professor of Engineering
Department of Mechanical and Aerospace Engineering
Case Western Reserve University
Cleveland, Ohio 44106-7222
rdq@case.edu
http://biorobots.case.edu

A. Professional Preparation

Institution	Location	Major	Degree &Year
The University of Akron	Akron, Ohio	Mechanical Engineering	B.S., 1980
The University of Akron	Akron, Ohio	Mechanical Engineering	M.S., 1983
Virginia Tech	Blacksburg, Virginia	Engineering Mechanics	Ph.D., 1985

B. Appointments

2003-Present	Arthur P. Armington Professor of Engineering, Case
1997-Present	Professor, Mechanical and Aerospace Engineering, Case
1992-Present	Director of CWRU Biorobotics Complex (http://biorobots.cwru.edu)
1992-97	Associate Professor, Mechanical and Aerospace Engineering, Case
1986-92	General Motors Assistant Professor, Case

C. Products

Five most relevant publications (out of more than 200 refereed publications):

1. Szczecinski, N. S., Hunt, A. J., Quinn, R. D. (2017). A functional subnetwork approach to designing synthetic nervous systems that control legged robot locomotion. Frontiers in Neurorobotics. DOI: 10.3389/fnbot.2017.00037.
2. Hunt, A. J., Szczecinski, N. S., Quinn, R. D. (2017). Development and training of a neural controller for hind leg walking in a dog robot. Frontiers in Neurorobotics 11(18). DOI: 0.3389/fnbot.2017.00018.
3. Szczecinski, N. S., Quinn, R. D. (2017). Template for the neural control of directed walking generalized to all legs of MantisBot. Bioinspiration and Biomimetics 12(4). DOI: 10.1088/1748-3190/aa6dd9. *Featured by* Bioinspiration and Biomimetics.
4. Alexander Hunt, Manuela Schmidt, Martin Fischer and Roger Quinn (2015) A biologically based neural system coordinates the joints and legs of a tetrapod *Bioinspir. Biomim.* **10** 055004, doi:10.1088/1748-3190/10/5/055004.
5. Rubeo, S., Szczecinski, N., Quinn, R. D. (2017). A Synthetic Nervous System Controls a Simulated Cockroach. *Applied Sciences, 8*(1), 6.

Five other relevant publications

1. Kaiyu Deng, Nicholas S. Szczecinski, Dirk Arnold, Emanuel Andrada, Martin Fischer, Roger D. Quinn, Alexander J. Hunt (2019) Neuromechanical Model of Rat Hind Limb Walking with Two-Layer CPGs, *Biomimetics* **2019**, *4*(1), 21; https://doi.org/10.3390/biomimetics4010021
2. Szczecinski, N. S., Quinn, R. D. (2018). Leg-local neural mechanisms for searching and learning enhance robotic locomotion. Biological Cybernetics. 112 (1-2), pp. 99-12, 2018/4/1, DOI: 10.1007/s00422-017-0726-x.

3. Szczecinski, N. S., Martin, J. P., Bertsch, D. J., Ritzmann, R. E., Quinn, R. D. (2015). Neuromechanical model of praying mantis explores the role of descending commands in pre-strike pivots. *Bioinspiration & Biomimetics, 10*(6), 065005.
4. Fletcher Young, Christian Rode, Alex Hunt, Roger Quinn (2019) Analyzing Moment Arm Profiles in a Full-Muscle Rat Hindlimb Model, *Biomimetics* **2019**, *4*(1), 10; https://doi.org/10.3390/biomimetics4010010
5. Mangan, E.V., Kingsley D.A., Quinn, R.D., Sutton, G.P., Mansour, J.M., Chiel, H.J. (2005) A biologically inspired gripping device. *Industrial Robot: An International Journal,* Vol. 32, No. 1. pp 49-54.

D. Synergistic Activities

- PI (2008-) Autonomous lawnmower, snow plow development with undergraduate researchers
  - Won ION Autonomous Lawnmower Competition 2009-11
  - Won ION Autonomous Snow Plow Competition 2017, 2019
- Co-Chair Organizing committee, Adaptive Motion of Animals and Machines (AMAM2008), Cleveland
- Co-Investigator for IGERT program in Neuromechanics (1999-2006)
- Co-Developed undergraduate course “Biorobotics Team Research” (2005 – Present)
- Undergraduate and High School Outreach: Host lab for undergraduate and high school researchers in robotics (1992 - Present); typically 30-40 undergraduate researchers in Biorobotics lab annually; multiple high school students work in the lab each summer; after-school program at local high school

Biographical Sketch

Cynthia A. Chestek, Associate Professor
North Campus Research Complex, Building 10, Room A171
2800 Plymouth Rd. Ann Arbor, MI 48105
734-707-3356, cchestek@umich.edu

A. PROFESSIONAL PREPARATION

College/University	Major	Degree & Year
Case Western Reserve University	Electrical Engineering	B.S., 2003
Case Western Reserve University	Electrical Engineering	M.S., 2005
Stanford University	Electrical Engineering	Ph.D., 2010
Stanford University	Neurosurgery Research	2010-2012

B. ACADEMIC/PROFESSIONAL APPOINTMENTS

Assistant Professor, Department of Biomedical Engineering, University of Michigan 2012-2018
Associate Professor, Department of Biomedical Engineering, University of Michigan 2018-current
(Courtesy appointments in Electrical Engineering, Neuroscience, and Robotics)

C. PUBLICATIONS

Publications Most Closely Related to Proposal

P. P. Vu, Z. T. Irwin, A. J. Bullard, S. L. Woo, I. C. Sando, M. G. Urbanchek, P. S. Cederna, **C. A. Chestek**. Closed-loop continuous hand control via chronic recording of regenerative peripheral nerve interfaces and intact muscle. *IEEE TNSRE,* 26(2): 10.1109/TNSRE.2017.2772961

K. E. Schroeder, Z. T. Irwin, M. Gaidica, J. N. Bentley, P. G. Patil, G. A. Mashour* and **C. A. Chestek***. Direct evidence for disrupted cortical communication during general anesthesia in the primate brain, *Neuroimage*, 134: 459-465, 2016. Link

Z. T. Irwin, K. E. Schroeder, P. Vu, D. M. Tat, A. Bullard, S. Woo, I. Sando, M. Urbanchek, P. Cederna and **C. A. Chestek**. Chronic recording of hand prosthesis control signals via a regenerative peripheral nerve interface in a rhesus macaque, *J Neural Eng,* 2016. Link

Z. T. Irwin, D. E. Thompson, K. E. Schroeder, D. M. Tat, A. Hassani, A. J. Bullard, S. L. Woo, A. J. Sachs, M. G. Urbanchek, W. C. Stacey, P. S. Cederna, P. G. Patil and **C. A. Chestek**. Enabling low-power multi-modal neural interfaces through a common low-bandwidth feature space, *IEEE Trans Neural Systems Rehabil Eng*, 99:1-11, 2015. Link

V. Gilja*. P. Nuyujukian*, C. Chestek, J. P. Cunningham, B. M. Yu, J. M. Fan, M. M. Churchland, M. T. Kaufman, J. C. Kao, S. I. Ryu, and K. V. Shenoy. "A high-performance neural prosthesis enabled by control algorithm design." Nature Neuroscience, 15: 1752-1757. Link

Other Significant Publications

P. R. Patel, K. Na, H. Zhang, T. D. Kozai, N. A. Kotov, E. Yoon, and **C. A. Chestek**. Insertion of linear 8.5 um diameter 16 channel carbon fiber electrode arrays for single unit recordings, *J Neural Eng*, 12(4):046009, 2015. Link

P. R. Patel, H. Zhang, M. T. Robbins, J. B. Nofar, S. P. Marshall, M. J. Kobylarek, T. D. Kozai, N. A. Kotov and **C. A. Chestek**. Chronic *in vivo* stability assessment of carbon fiber microelectrode arrays. *J Neural Eng*, 13(6):066002, 2016. Link

C. Chestek, V. Gilja, P. Nuyujukian, J. Foster, J. Fan, M. Kaufman, M. Churchland, Z. Rivera-Alvidrez, J. Cunningham, S. Ryu, and K. Shenoy. “Long-term stability of neural prosthetic control signals from silicon cortical arrays in rhesus macaque motor cortex,” J. of Neural Eng., 8: 1-11, 2011. Link

C. Chestek*, A. P. Batista*, G. Santhanam, B. M. Yu, A. Afshar, J. P. Cunningham, V. Gilja, S. I. Ryu, M. M. Churchland, and K. V. Shenoy. "Single-Neuron Stability During Repeated Reaching in Macaque Premotor Cortex," *J Neurosci*, 27:10742-10750, 2007. Link

C. Chestek, V. Gilja, C. H. Blabe, B. L. Foster, K. V. Shenoy, J. Parvizi, and J. M. Henderson. “Hand posture classification using electrocorticography signals in the gamma band over sensorimotor brain areas.” J Neural Eng, 10:1-11, 2013. Link

D. SYNERGISTIC ACTIVITIES

Journal Reviewer, IEEE TNSRE, IEEE TBioCAS, IEEE EMBS, J Neurophysiology, Nature Neuroscience, Neural Computation
Membership, IEEE, IEEE Women in Engineering, Society for Neuroscience
Women in Science and Engineering – Summer prosthetics workshop
Committee member – Robotics Day (3 yrs)

Hillel J. Chiel
Professor of Biology
Case Western Reserve University

a. Professional Preparation

Yale University	(New Haven, Conn.)	English	B.A. 1974
Mass. Inst. Technology	(Cambridge, Mass.)	Nutrition and Metabolism	M.S. 1976
Mass. Inst. Technology	(Cambridge, Mass.)	Neural and Endocrine Regulation	Ph.D. 1980
Columbia University	(New York, NY)	Neurobiology and Behavior	1980-1985

b. Appointments

1999-	Professor, Departments of Biology, Neurosciences, and Biomedical Engineering, Case Western Reserve University, Cleveland Ohio.
1992-1999	Associate Professor, Dept. Biology, Case Western Reserve University, Cleveland Ohio.
1989-1992	Assistant Professor, Dept. Neurosciences, Case Western Reserve, Cleveland, Ohio.
1987-1992	Assistant Professor, Dept. Biology, Case Western Reserve University, Cleveland Ohio.
1985-1987	Consultant in Neurobiology, Department of Molecular Biophysics, AT&T Bell Laboratories, Murray Hill, New Jersey.

c. Publications. (* Indicates publications resulting from prior NSF support.)

Five publications closely related to the present proposal:

*1. McManus, J.M., **Chiel**, H.J., Susswein, A.J. (2019) Successful and unsuccessful attempts to swallow in a reduced *Aplysia* preparation regulate feeding responses and produce memory at different neural sites. Learn Mem. 26(5):151-165. doi: 10.1101/lm.048983.118.

*2. Park, Y., Shaw, K., **Chiel, H.,** and Thomas, P. (2018). The infinitesimal phase response curves of oscillators in piecewise smooth dynamical systems. *European Journal of Applied Mathematics,* 1-36. doi:10.1017/S0956792518000128.

*3. Lyttle, D. N., Gill, J. P., Shaw, K. M., Thomas, P. J. and **Chiel, H. J.** (2017) Robustness, flexibility and sensitivity in a multifunctional motor control model. Biological Cybernetics. 111: 25 – 47.

*4. Cullins, M. J., Gill, J. P., McManus, J. M., Lu, H., Shaw, K. M. and **Chiel, H. J.** (2015) Sensory feedback reduces individuality by increasing variability within subjects. Current Biology. 25:2672-2676.

*5. Lu, H., McManus, J.M., Cullins, M. J. and **Chiel, H. J.** (2015) Preparing the periphery for a subsequent behavior: Motor neuronal activity during biting generates little force but prepares a retractor muscle to generate larger forces during swallowing in *Aplysia* Journal of Neuroscience, 35:5051 – 5066.

Five additional publications:

*1. Ganguly, M., Jenkins, M.W., Jansen, E.D., **Chiel, H.J.** (2019) Thermal block of action potentials is primarily due to voltage-dependent potassium currents: a modeling study. J Neural Eng. 16(3):036020. doi: 10.1088/1741-2552/ab131b.

*2. Kandhari, A., Huang, Y., K A Daltorio, K.A., **Chiel, H.J.** and Quinn, R.D. (2018) Body stiffness in orthogonal directions oppositely affects worm-like robot turning and straight-line locomotion. Biomimetics and Bioinspiration. 13: 026003, doi: https://doi.org/10.1088/1748-3190/aaa342.

3. Kodama, N. X., Feng, T., Ullett, J. J., **Chiel, H. J.,** Sivakumar, S. S., Galán, R. F. (2018) Anti-correlated cortical networks arise from spontaneous neuronal dynamics at slow timescales. Scientific Reports 8:

Article Number 666, doi:10.1038/s41598-017-18097-0.

4. Lothet, E. H., Shaw, K. M., Lu, H., Zhuo, J., Wang, Y. T., Gu, S., Stolz, D. B., Jansen, E. D., Horn, C.C., **Chiel, H. J.** and Jenkins, M. W. (2017) Selective inhibition of small-diameter axons using infrared light. Scientific Reports 7:3275, pp. 1 - 8. DOI:10.1038/s41598-017-03374-9.

*5. Cullins, M. J., Shaw, K. M., Gill, J. P., and **Chiel, H. J.** (2015) Motor neuronal activity varies least among individuals when it matters most for behavior. Journal of Neurophysiology, 113: 981 - 1000.

d. Synergistic Activities

- **(i)** Developed a course, *Dynamics of Biological Systems*, that teaches undergraduates the principles of modeling biological systems using *Mathematica* and principles from nonlinear dynamical systems theory. Course is a core requirement for BS degree in Systems Biology. This course received the *Science* prize for Inquiry-Based Instruction (2012).
- **(ii)** Elected Fellow of the Institute of Physics, England (2004).
- **(iii)** Wittke Award for Excellence in Undergraduate Teaching (2004).
- **(iv)** Diekhoff Award for Excellence in Graduate Teaching (2009).

Charles J. Heckman, PhD
Department of Physiology
Northwestern University Feinberg School of Medicine, Chicago IL 60611

Professional Preparation

Oberlin College, OH	Biology	A.B.	1975
University of Washington, WA	Kinesiology	M.S.	1983
University of Washington, WA	Physiology & Biophysics	Ph.D.	1986
Lab of Neural Control, NIH, MD	Neurophysiology	Post-doc	1988
Northwestern University, IL	Neurophysiology	Post-doc	1990

Appointments

05/88 - 11/90	Research Associate, Department of Physiology, Northwestern University, Feinberg School of Medicine, Chicago, IL
12/90 - 12/96	Research Assistant Professor, Department of Physiology, Northwestern University, Feinberg School of Medicine, Chicago, IL
12/96 - 08/98	Research Associate Professor, Department of Physiology, Northwestern University, Feinberg School of Medicine, Chicago, IL
09/98 - 08/05	Associate Professor, Departments of Physiology and Physical Medicine and Rehabilitation, Northwestern University, Feinberg School of Medicine, Chicago and the Rehabilitation Institute of Chicago, IL
09/05 -	Professor, Departments of Physiology and Physical Medicine and Rehabilitation, Northwestern University, Feinberg School of Medicine, Chicago and the Rehabilitation Institute of Chicago, IL
01/10 -	Adjunct Professor, Department of Physical Therapy and Human Movement Science, Northwestern University Feinberg School of Medicine, Chicago IL
01/10 -	Associate Chair for Research, Department of Physical Therapy and Human Movement Science, Northwestern University Feinberg School of Medicine, Chicago IL

Five publications most closely related to the proposed project

Lee, R.H. and Heckman, C.J. Adjustable amplification of synaptic input in the dendrites of spinal motoneurons in vivo. *J. Neurosci.* 20: 6734-6740, 2000. PMID: 10964980

Johnson, M.D, Kajtaz, E., Cain, C.M., and Heckman, C.J. Motoneuron intrinsic properties, but not their receptive fields, recover in chronic spinal injury. *J. Neurosci.* 33(48): 18806-18813, 2013. PMC3841450

Hyngstrom, A.S., Johnson, M.D., Schuster, J. and Heckman, C.J. Movement-related receptive fields of spinal motoneurones with active dendrites. *J. Physiol.* 586, 1581-93, 2008. PMC2375694

Manuel, M. and Heckman, C.J. Adult mouse motor units develop almost all of their force in the sub-primary range: a new all-or-none strategy for force recruitment? *J. Neurosci*. 31(42): 15188-15194, 2011. PMC3210508

Powers, R.K. and Heckman, C.J. Synaptic control of the shape of the motoneuron pool input-output function. *J. Neurophysiol*. 117:1171-1184, 2017. PMC5350877

Five other significant publications

Hyngstrom, A.S., Johnson, M.D., Miller, J.F. and Heckman, C.J. Intrinsic electrical properties of spinal motoneurons vary with joint angle. *Nature Neuroscience*, 10: 363-9, 2007. PMID: 17293858

Murray KC, Nakae A, Stephens MJ, Rank M, D'Amico J, Harvey PJ, Li X, Harris RL, Ballou EW, Anelli R, Heckman CJ, Mashimo T, Vavrek R, Sanelli L, Gorassini MA, Bennett DJ, Fouad, Recovery of motoneuron and locomotor function after spinal cord injury depends on constitutive activity in 5-HT2C receptors. *Nature Med.* 2010 16(6): 694-700. PMC3107820

Johnson, M.D., Hyngstrom, A.S., Manuel, M., Heckman, C.J. Push-pull control of motor output. *J. Neurosci.* 32(13): 4592:4599, 2012. PMC3335194

Wei, K, Glaser, J.I., Deng, L., Thompson, C.K., Stevenson, I.H., Wang, Q., Hornby, T.G., Heckman, C.J., Kording, K.P. Serotonin affects movement gain control in the spinal cord. *J. Neurosci. 34: 12690-700*, 2014. PMC4166156

Thompson, C.K., Negro, F., Johnson, M.D., Holmes, M.R., McPherson, L.M., Powers, R.K., Farina, D., and Heckman, C.J. Robust and accurate decoding of motoneuron behavior and prediction of the resulting force output. *J. Physio*l. 596: 2643-59, 2018. PMC6046070

Synergist activities

Promoting collaborative environments: Played a key role in initiating and organizing the International Motoneuron Society, which supports a series of bi-annual meetings starting in 2000 and continuing to the present. Co-organized the 2000, 2004 and 2018 meetings at the University of Colorado and have been on the Society board since its inception. This is the preeminent meeting for spinal motoneurons with attendees from a wide range of institutions in the United States and Canada as well as many European (e.g. France, the United Kingdom, the Netherlands, Italy, Turkey) and Asian countries (e.g. China, South Korea).

Promoting research collaborations: PI (initial version) and then M-PI (renewal) on a major NIH/NINDS grants to study the mechanisms of ALS using a mouse model. This collaboration involves the University of Washington (Seattle), Northwestern University (Chicago) and Descartes Universitie (Paris). The focus is unique, on dysregulation of homeostasis for excitability of motoneurons.

Service to the neuroscience community: Member of over 50 NIH and NSF review panels over the past 25 years, as both an ad hoc member and regular member (BNVT, 2013-16, Chair 2014-16).

Service for ethics in science: Member of the Northwestern IACUC since 2000, Vice Chair from 2002-5, Chair since 2005. During this time, led the efforts to transition to electronics forms and provided consistent guidance and to help colleagues to maintain good quality animal care.

Graduate education: Member of the Board of the Northwestern University Interdepartmental Neuroscience program (NUIN), from 2012 onwards. Primary role at present is as an advisor to first year graduate students in this program. In addition, initiated a new core course for NUIN, with the goal of teaching math, statistics and engineering concepts to systems neuroscience graduates that lack this background. The course has been successful and is in its 5th year.

Matthew Tresch
Professor
Department of Biomedical Engineering, Physical Medicine and Rehabilitation, Physiology
Northwestern University, Shirley Ryan AbilityLab
Chicago, IL 60611
312-503-1373
m-tresch@northwestern.edu

(a) Professional Preparation

Institution	Location	Major/area	Degree &Year
Wesleyan University	Middletown, CT	psychology	BA, 1992
Massachusetts Institute of Technology	Cambridge, MA	neuroscience	PhD, 1997
University of Copenhagen	Copenhagen, Denmark	spinal cord	2001

(b) Appointments

2019-present	Professor, Biomedical Engineering/Physical Medicine and Rehabilitation/Physiology, Northwestern
2011-2019	Associate Professor, Biomedical Engineering/Physical Medicine and Rehabilitation/Physiology, Northwestern
2005-2011	Assistant Professor, Biomedical Engineering/Physical Medicine and Rehabilitation/Physiology, Northwestern
2001-2005	Research Scientist, Massachusetts Institute of Technology

(c) Publications

(i) List up to five (5) publications/products most closely related to the proposed project

1. Alessandro C, Rellinger BA, Barroso FO, Tresch MC (2018) Adaptation after vastus lateralis denervation in rats demonstrates neural regulation of joint stresses and strains. Elife, 7, e38215.
2. Sandercock TG, Wei Q, Dhaher YY, Pai DK, Tresch MC (2018) Vastus lateralis and vastus medialis produce distinct mediolateral forces on the patella but similar forces on the tibia in the rat. J. Biomech, 81:45-51.
3. Wei Q, Pai DK, Tresch MC (2018) Uncertainty in limb configuration makes minimal contribution to errors between observed and predicted forces in a musculoskeletal model of the rat hindlimb, Trans. Biomed. Eng. 65(2):469-476.
4. Tysseling VM, Klein DA, Imhoff-Manuel R, Manuel M, Heckman CJ, Tresch MC. (2017) Constitutive activity of 5-HT2c receptors is present following incomplete spinal cord injury but is not modified after chronic SSRI or baclofen treatment. J Neurophysiol. 118(5):2944-2952.
5. Chowdhury RH, Tresch MC, Miller LE. (2017) Musculoskeletal geometry accounts for apparent extrinsic representation of paw position in dorsal spinocerebellar tract. J Neurophysiol. 118(1):234-242.

(ii) List up to five (5) other significant publications/products, whether or not related to the proposed project.

1. Berniker M, Jarc A, Kording K, Tresch M. (2016) A probabilistic analysis of muscle force uncertainty for control. IEEE Trans Biomed Eng. 63: 2359-2367.
2. Wu M, Pai DK, Tresch MC, Sandercock TG (2012) Passive elastic properties of the rat ankle. J. Biomech. 1;45(9):1728-32.

3. Tresch MC, Jarc A (2009) The case for and against muscle synergies Curr Opin Neurobiol. 19(6):601-7.
4. Tresch MC and Kiehn O (2000) Motor coordination without action potentials in the mammalian spinal cord. Nature Neuroscience 3: 593-599.
5. Tresch MC, Saltiel P, and Bizzi E (1999) The construction of movement by the spinal cord. Nature Neuroscience, 2:162-167.

(d) Synergistic Activities

1. Associate Editor, Journal of Neurophysiology, 2018-present
2. Chair of Scientific Review , Paralyzed Veterans of America , 2014-2016
3. Northwestern University Presidential Fellows Review Panel, 2014-present
4. International Society for Electrophysiology and Kinematics, Scientific Chair, 2016
5. Co-director for NSF-REU for Summer Internships in Neural Engineering (SINE) at the Rehabilitation Institute of Chicago and Northwestern, 2007-2009.

Biographical Sketches of Foreign Participants

Ansgar Büschges, Dr. rer. nat.
Full Professor for Animal Physiology and Neurobiology
Department of Biology, Institute of Zoology
Faculty of Mathematics and Natural Sciences
University of Cologne
Zülpicher Strasse 47b, 50674 Cologne, GER
ansgar.bueschges@uni-koeln.de
http://www.zoologie.uni-koeln.de/bueschges.html?&L=1

A. Professional Preparation

Institution	Location	Major	Degree &Year
University of Bielefeld	Bielefeld, GER	Biology	Dipl.Biol., 1986
University of Kaiserslautern	Kaiserslautern, GER	Biology	Dr.rer.nat. 1989
University of Kaiserslautern	Kaiserslautern, GER	Zoology	Habilitation, 1995

B. Appointments

1998-present	Full Professor for Animal Physiology & Neurobiology, University of Cologne, Cologne, GER
1997-1998	DFG Heisenberg Fellow, University of Kaiserslautern, Kaiserslautern, GER and Karolinska Institutet, Stockholm, SWE
1991-1997	Research Associate, University of Kaiserslautern, Kaiserslautern, GER
1989-91	Postdoctoral Fellow, AHFMR, University of Alberta, Edmonton Alberta, CDN
1986-89	PhD student, University of Kaiserslautern, Kaiserslautern, GER

C. Products

Five most relevant publications (out of more than 110 refereed publications):

1. von Twickel, A., Guschlbauer, C., Hooper, S.L., Büschges, A. (2019). Swing velocity profiles of small limbs can arise from transient passive torques of the antagonist muscle alone. Current Biology Jan 7;29(1):1-12.e7.
2. Szczecinski, N.S., Bockemühl, T., Chockley, A.S., Büschges, A. (2018). Static stability predicts the continuum of interleg coordination patterns in *Drosophila.* J. Exp. Biol. 221, (Pt 22). pii: jeb189142. doi: 10.1242/jeb.189142.
3. Mantziaris C., Bockemühl, T., Holmes, P., Daun, S., Büschges, A. (2017). Intersegmental influences between central pattern generating networks in the walking system of the stick insect. J. Neurophysiol. 118: 2296-2310.
4. Zill, S.N., Neff, D., Chaudry, S., Exter, A., Schmitz, J., Büschges, A. (2017). Effects of force detecting sense organs on muscle synergies are correlated with their response properties. Arthropod, Structure and Development 46: 564-578.
5. Gruhn, M., Rosenbaum, P., Bockemühl, T., Büschges, A. (2016). Body side-specific control of motor activity during turning in a walking animal. eLife 10.7554/eLife.13799

Five other relevant publications

1. Bidaye, S.S., Bockemühl, T., Büschges, A. (2018). Six-legged walking in insects: how CPGs, peripheral feedback, and descending signals generate coordinated and adaptive motor rhythms. J. Neurophysiol. 119: 459-475.
2. Hooper, S.L., Büschges A. (2017). Neurobiology of Motor Control – Fundamental Concepts and New Directions. S.L. Hooper & A. Büschges (eds.) Wiley Blackwell.

3. Berendes, V., Zill, S.N., Büschges, A., Bockemühl, T. (2016). Speed-dependent interplay between local pattern-generating activity and sensory signals during walking in *Drosophila.* J. Exp. Biol. 219: 3781-3793.
4. Buschmann, Th., Ewald, A., von Twickel, A., Büschges, A. (2015). Controlling Legs for Locomotion - Insights from Robotics and Neurobiology. Bioinspiration and Biomimetics 10(4): 041001.
5. Berg, E.M., Hooper, S.L., Schmidt, J., Büschges, A. (2015). A leg-local neural mechanism mediates the decision to search in stick insect. Current Biology 25 (15): 2012-7.

D. Synergistic Activities

- 2008-2016: member of the *DFG-Study Section Neurosciences* (206-05)
- 2012 – present: Member of the *Academy of Science and Arts of North Rhine-Westphalia,* GER
- 2014 – present: Speaker of the DFG-funded RTG "*Neural Circuit Analysis on the cellular and subcellular level*" at UoC in the Neurosciences with presently 14 PIs and 25 doctoral students
- 2015 – present: Member of the Executive Board of the "German Academic Scholarship Foundation"
- 2016: Co-Organizer of the International Meeting at HHMI Janelia Research Campus "*Motor Control Circuits: Structure, Function and Behavior*", Ashburn, USA

Biographical Sketches of Foreign Participants

Kei Ito, PhD

Full Professor for Experimental Morphology and Neuroanatomy, AXA Chair
Department of Biology, Institute of Zoology
Faculty of Mathematics and Natural Sciences
University of Cologne
Zülpicher Strasse 47b, 50674 Cologne, GERMANY
k.ito@uni-koeln.de
http://www.zoologie.uni-koeln.de/ito.html

A. Professional Preparation

Institution	**Location**	**Major**	**Degree &Year**
The University of Tokyo	Tokyo Japan	Biophysics	B.S., 1986
The University of Tokyo	Tokyo Japan	Biophysics	M.S., 1988
The University of Tokyo	Tokyo Japan	Biophysics	Ph.D., 1991

B. Appointments

2017-Present	AXA Chair "From Genome to Structure and Function", Institute of Zoology, University of Cologne, Germany
2016-Present	Full Professor for Experimental Morphology and Neuroanatomy, Institute of Zoology, University of Cologne, Germany
2015-Present	Senior Fellow, Howard Hughes Medical Institute (HHMI) Janelia Research Campus, Ashburn, VA, United States
2002-2018	Associate Professor, Institute of Molecular and Cellular Biosciences, University of Tokyo, Japan
1998-2002	Assistant Professor, National Institute for Basic Biology, Okazaki, Japan
1994-1998	Senior Research Fellow, Yamamoto Behaviour Genes Project, ERATO, JST, Japan
1991-1994	Postdoctoral Research Fellow, Institute of Genetics, University of Mainz, Germany

C. Products

Five most relevant publications (out of more than 70 refereed publications):

1. Murtin, C., Frindel, C., Rousseau, D., and Ito, K. Image processing for precise three-dimensional registration and stitching of thick high-resolution laser-scanning microscopy image stacks. Computers in Biology and Medicine, 92, 22-41, 2018.
2. Tsubouchi, A., Yano, T., Yokoyama, T.K., Murtin, C., Otsuna, H., and Ito, K. Topological and modality-specific representation of somatosensory information in the fly brain. Science 358, 615-623, 2017.
3. Ito. K., Shinomiya, K., Ito, M., Armstrong, D., Boyan, G., Hartenstein, V., Harzsch, S., Heisenberg, M., Homberg, U., Jenett, A., Keshishian. H., Restifo, L., Rössler, W., Simpson, J., Strausfeld, N. J., Strauss, R., and Vosshall, L.B; The Insect Brain Name Working Group. A systematic nomenclature for the insect brain. Neuron, 81, 755-765, 2014.
4. Ito, M., Masuda, N., Shinomiya, K., Endo, K., and Ito, K. Systematic analysis of neural projections reveals clonal composition of the *Drosophila* brain. Curr. Biol, 23, 644–655, 2013.
5. Kamikouchi, A., Inagaki, H. K., Effertz, T., Fiala, A., Hendrich, O., Gopfert, M. C. and Ito, K. The neural basis of *Drosophila* gravity sensing and hearing. Nature, 458, 165-171, 2009.

Five other relevant publications

6. Matsuo, E., Seki, H., Asai, T., Morimoto, T., Miyakawa, H., Ito, K., and Kamikouchi, A. Organization of projection neurons and local neurons of the primary auditory center in the fruit fly *Drosophila melanogaster.* J. Comp. Neurol. 524, 1099-1164, 2016.
7. Flood, T., Iguchi, S., Gorczyca, M., White, B., Ito, K., and Yoshihara, M. A single pair of interneurons commands the *Drosophila* feeding motor program. Nature 499, 83-87, 2013.
8. Tanaka, N. K., Endo, K. and Ito, K. The organization of antennal lobe-associated neurons in the adult *Drosophila melanogaster* brain. J Comp Neurol, 520: 4067-4130, 2012.
9. Miyazaki, T. and Ito, K. Neural architecture of the primary gustatory center of *Drosophila melanogaster* visualized with GAL4 and LexA enhancer-trap systems. J Comp Neurol, 518, 4147–4181, 2010.
10. Otsuna, H., Shinomiya, K., and Ito.K. Parallel neural pathways in higher visual centers of the *Drosophila* brain that mediate wavelength-specific behavior. Front. Neural Circuits, 8, 8, 2014.

D. Synergistic Activities

- Administrator of the ANN Arthropod Neuroscience Network (https://ann.uni-koeln.de/) and ANN mailing list for arthropod neuroscience researchers (2017-present)
- Administrator of the Jfly Data depository for *Drosophila* researchers (http://jfly.iam.u-tokyo.ac.jp) and Jfly Mailing list for Japanese-speaking *Drosophila* researchers (1995-2019)
- Editorial board of Arthropod Structure and Development (2002-present)
- Study section member for the research grants of the Japan Society for the Promotion of Science in the field of general neurobiology (2006-2018) as well as for the institutional grants for the promotion of young and female scientists in Japan (2009-2011).
- Vice President of a non-profit organization "Color Universal Design Organization" (2004-present); Consultation and advices for companies like Adobe, Panasonic, Sharp, NEC, Olympus, Ricoh, Toyota, Tokyo Subway, Japan Paint Manufacturers Association, Japan Printing Industry Association, etc.), Awarded prize; Japan Good Design Award (2008), Prime Minister's Award for the Promotion of Inclusive Design (2010)

Biographical Sketches of Foreign Participants

Prof. Dr. Dr. h.c. Martin S. Fischer

Professor of Systematic Zoology and Evolutionary Biology

Institut für Spezielle Zoologie und Evolutionsbiologie mit Phyletischem Museum

Friedrich-Schiller-Universität Jena

Erbertst.t 1

D- 07743 Jena

Martin.Fischer@uni-jena.de

A. Professional Preparation

Institution	Major / Area	Degree, Year or Dates
Undergraduate: University of Tübingen, Germany and University of Paris VI, France	Biology/Geology	Diploma 1983
Graduate: University of Tübingen, Germany	Biology	Dr.rer.nat. 1986
Postdoctoral: University of Frankfurt and Tübingen, Germany	Anatomy/Zoology	1986-1993

B. Appointments

Director, Institute of Zoology and Evolutionary Research with Phyletic Museum, 1993 - Present
Full Professor, Systematic Zoology und Evolutionary Biology, University Jena 1993 – Present
Assistant Professor, Institute of Zoology, University of Tübingen, 1987 - 1993
Assistant Professor, Zentrum der Morphologie, University of Frankfurt, 1986 - 1987

C. Products

Five most relevant publications (out of more than 150 refereed publications):

Five Most Closely Related to Current Project

1. Fischer, M.S.; N. Schilling, N.; M. Schmidt, M. and H. Witte (2002) Basic limb kinematics of small therian mammals. *J. exp. Biol*. **205**: 1315-1338.
2. Fischer, M.S. and H.F. Witte. (2007) Legs evolved only at the end! *Phil Trans. R. Soc*. A. **365**: 185-198.
3. Hunt, A., Schmidt, M., Fischer, M.S. and R. Quinn (2015) A biologically based neural system coordinates the joints and legs of a tetrapod *Bioinspir. Biomim.* **10** 055004, doi:10.1088/1748-3190/10/5/055004.
4. Fischer, M.S., Lehmann, S. and E. Andrada (2018) Three-dimensional kinematics of canine hind limbs: in vivo, biplanar, high-frequency fluoroscopic analysis of four breeds during walking and trotting. *Scientific Rep.* (2018) 8:16982 | DOI:10.1038/s41598-018-34310-0 : 1-22
5. Nyakatura J.A., Melo, K., Horvat, T., Karakasiliotis, K., Allen, V.R., Andikfar, A., Andrada, E., Arnold, P., Lauströer, J., Hutchinson, J.R., Fischer, M.S. and A.J. Ijspeert. (2019) Reverse-engineering the locomotion of a stem amniote," *Nature*, vol. 565, no. 7739, p. 351, Jan. 2019.

Five other relevant publications

6. Fischer, M.S. (1994) Crouched posture and high fulcrum, a principle in the locomotion of small mammals: the example of the rock hyrax (Procavia capensis)(Mammalia: Hyracoidea). *J. Human Evol.* 26 (5-6), 501-524
7. Fischer, M.S. (2001) Locomotory organs of Mammals: New mechanics and feed-back pathways but conservative central control. *Zoology* **103**: 230-239.
8. Ritzmann, R.E., R.D. Quinn and M.S. Fischer (2004) Convergent Evolution and Locomotion through Complex Terrain by Insects, Vertebrates and Robots. *Arthopod Struct. Dev.* **33**:361-379.
9. Fischer, M.S. and R. Blickhan (2006) The tri-segmented limbs of therian mammals: kinematics, dynamics, and self-stabilization. A review. *J. exp. Zool.* **305A**: 935-952.
10. Fischer, M.S. and K.E. Lilje (2011) Dogs in motion. Dortmund. 208 pages.

Synergistic Activities

- Member of 37 search committees in five different faculties in Jena and other universities
- Hosted IARP-Workshop: Biologically Motivated Service Robotics (with Dr. h.c. Lothar Späth) 1999.
- Hosted Workshop on "Autonomous Walking" (with Prof. Dr. H. Witte) 2000.
- Worked actively in German Council of Science and Humanities and German Research Council
- Worked with Festo AG since 2006 in Bionic learning networks showing four times robots from collaborations at the Hannover fare

Biographical Sketches of Foreign Participants

Dr. Jan M. Ache

Junior Group Leader
Department of Neurobiology and Genetics
University of Würzburg
97074 Würzburg, Germany

Phone: +1 571-209-3380
achej@janelia.hhmi.org

A. Professional Preparation

Institution	Location	Subject	Degree & Year
University of Cologne	Cologne, Germany	Biology	B.Sc. (2008)
University of Cologne	Cologne, Germany	Neuroscience	M.Sc. (2010)
University of Bielefeld	Bielefeld, Germany	Biology	Dr. rer. Nat. (2015)
HHMI, Janelia	Ashburn, Virginia, USA	Neuroscience	Postdoc (2014 - 2017)

B. Appointments

Starting 10/2019	Junior Group Leader, University of Würzburg, Würzburg, Germany
9/2017 - present	Research Scientist, HHMI, Janelia Research Campus, Ashburn, VA, USA

C. Products

Five most relevant publications (on descending motor control):

1. **Ache, JM**, Namiki, S, Lee, A, Branson, K, and Card, G (2019): 'State-dependent decoupling of sensory and motor circuits underlies behavioral flexibility *in Drosophila*', **Nature Neuroscience** (in press)

2. **Ache, JM**, Polsky, J, Alghailani, S, Parekh, R, Breads, P, Peek, M, Bock, D, von Reyn, C and Card, GM (2019): 'Neural basis for looming size and velocity encoding in the Drosophila Giant Fiber escape pathway', **Current Biology** 29 (6), 1073-1081

3. **Ache, JM** and Dürr, V (2015): 'A computational model of a descending mechanosensory pathway involved in active tactile sensing', **PLoS Computational Biology** 11 (7), e1004263

4. **Ache, JM**, Haupt, SS and Dürr, V (2015): 'A direct descending pathway informing locomotor networks about tactile sensor movement, **Journal of Neuroscience** 35 (9), 4081-4091

5. **Ache, JM** and Dürr, V (2013): 'Encoding of near-range spatial information by descending interneurons in the stick insect antennal mechanosensory pathway', **Journal of Neurophysiology** 110 (9), 2099-2112

Two other relevant publications (on biomechanics and motor control):

1. **Ache, JM** and Matheson, T (2013): 'Passive joint forces are tuned to limb use in insects and drive movements without motor activity', **Current Biology** 23 (15), 1418-1426

2. **Ache, JM** and Matheson, T (2012): 'Passive resting state and history of antagonist muscle activity shape active extensions in an insect limb', **Journal of Neurophysiology** 107 (10), 2756-2768

D. Synergistic Activities

- **Faculty member & Teaching assistant, Marine Biological Laboratory, MA** (2015 & 2016)
  I taught a two-week course module on the neural control of flight as part of the Neural Systems and Behavior course, an international summer course for graduate students, postdocs, and faculty members focusing on disseminating experimental approaches and techniques to the neuroscience community. I was a teaching assistant in 2015 and a faculty member in 2016.

- **Member of the Developing Neuroethology Award Committee** (2019 - present)
  Awarding grants to support the participation of scientists from emerging and developing countries in the International Congress of Neuroethology, organized by the Society for Neuroethology.

- **High School Student mentoring** (2016 - 2018)
  I mentored two high school students, who carried out behavioral genetics studies under my supervision for a six-week summer internship in 2016. One of them returned for a second project the following year and kept working with me as a student technical assistant until 2018. She is now an undergraduate at Harvard.

- **Public outreach: Science Slams**
  I presented my PhD research to the general public as part of the international science outreach effort 'FameLab', organized by the British Council (UK) and during other events. I won several awards at FameLab science slam competitions in 2012, including 1st prize of the Audience, FameLab Germany (nationwide competition) and 1st prize of the Jury, FameLab North Rhine-Westphalia (statewide competition).
  See http://tinyurl.com/q5v4e9x or http://tinyurl.com/j6bmb9v for examples (in German).

Biographical Sketches of Foreign Participants

GREGORY P. SUTTON
Professor
School of Life Sciences
University of Lincoln
Bristol, UK, BS8 1UG
+44 (0) 7807451914
RScealai@gmail.com

PROFESSIONAL PREPARATION

2000	Case Western Reserve University	B.S.	Mechanical Engineering
2000	Case Western Reserve University	M.S.	Mechanical Engineering
2006	Case Western Reserve University	Ph.D.	Mechanical Engineering

APPOINTMENTS

2019 – Current	**Professor (Full)**	School of Life Sciences University of Lincoln (UK)
2016 – Current	**Research Scientist**	Biology Department Duke University (USA)
2011 – 2018	**Research Fellow**	School of Life Sciences University of Bristol
2006 - 2011	**Research Fellow**	Department of Zoology University of Cambridge

Five most relevant publications:

1 **Sutton GP**, Doroshenko M, Cullen DA, Burrows M (2016) Take-off speed in jumping mantises depends on body size and a power limited mechanism. ***Journal of Experimental Biology*** 219: 2127-2136.

2 **Sutton GP**, Clarke D, Morley EL, Robert D (2016). Mechanosensory hairs in bumble bees (*Bombus terrestris*) detect weak electric fields. ***Proceedings of the National Academy of Sciences of the United States of America*** 113(26) 7261-7265.

3 **Sutton, GP**, Mangan, EV, Neustadter, DM, Beer, RD, Crago, PE, Chiel, HJ (2004). Neural control exploits changing mechanical advantage and context dependence to generate different feeding responses in *Aplysia*. *Biological Cybernetics* 91, 333-345.

4 Rogers SM, Riley J, Brighton C, **Sutton GP**, Cullen DA, Burrows M (2016). Increased muscular volume and cuticular specialisations enhance jump velocity in solitarious compared with gregarious desert locusts, *Schistocerca gregaria*. ***Journal of Experimental Biology*** 219(5): 635-648.

5 Ilton M, Bhamla S, Ma D, Cox SM, Azizi M, Bergbreiter S, Guo A, Kim Y, Koh, J, Krishnamurthy D, Kuo C, Temel ZF, Fitchett LL, **Sutton GP**, Crosby AJ, Prakash M, Wood RJ, and Patek SN (2018). The principles of cascading power limits in small, fast biological and engineered systems. ***Science*** 360 (6387) eaao1082.

Five other significant publications

1 **Sutton GP**, Burrows M (2011). The biomechanics of the jump of the flea. ***Journal of Experimental Biology*** 214, 836 - 847.

2 Rosario MV, **Sutton GP**, Patek SN, and Sawicki GS (2016). Muscle-spring dynamics in time-limited, elastic movements. ***Proceedings of the Royal Society of London B*** **283**: 20161561.

3 Burrows M and **Sutton GP** (2013). Interacting gears synchronize propulsive leg movements in a jumping insect. ***Science*** 341(6151) 1254-1256.

4 Novacovic VA, **Sutton GP**, Neustadter DM, Beer RD, Chiel HJ (2006). Mechanical reconfiguration mediates swallowing and rejection in *Aplysia californica*. *Journal of Comparative Physiology A*, 192: 857-870. (Novacovic and Sutton are co-first authors)

5 Drushel RF, **Sutton GP**, Neustadter DM, Mangan EV, Adams BW, Crago PE, Chiel HJ (2002). Radula-centric and odontophore centric kinematic models of *Aplysia californica*. *Journal of Experimental Biology* 205 (14) 2029-2051.

SYNERGISTIC ACTIVITIES

Assisted in the development of *Dynamics of Biological Systems*, which teaches undergraduates the principles of modeling biological systems using *Mathematica* and principles from nonlinear dynamical systems theory. Course is a core requirement for new BS degree in Systems Biology at Case Western Reserve University.

Biographical Sketches of Foreign Participants

Alexander Blanke, PhD
ERC Research Group Leader, Institute for Zoology, Biocenter
University of Cologne, Germany
a.blanke@uni-koeln.de
http://www.zoologie.uni-koeln.de/blanke.html

A. Professional Preparation

Institution	Location	Major	Degree &Year
University of Bonn	Bonn, Germany	Biology	Diploma, 2007
University of Bonn	Bonn, Germany	Zoology	Ph.D., 2013

B. Appointments

since 2018	ERC Group Leader, Morphological Dynamics, University of Cologne
2015 - 17	Postdoc, Medical and Biological Engineering, University of Hull, UK
2014 - 15	Postdoc, Comparative Embryology, University of Tsukuba, Japan

C. Products

Five most relevant publications:

1. Yoshizawa, K., Kamimura, Y., Lienhard, C., Ferreira, R. L., **Blanke**, A. 2018. A biological switching valve evolved in the female of a sex-role reversed cave insect to receive multiple sperm packages. eLIFE 7:e39563. DOI: https://doi.org/10.7554/eLife.39563.
2. **Blanke**, A., Pinheiro, M., Watson, P. J., Fagan, M. J. 2018. A biomechanical analysis of prognathous and orthognathous insect head capsules: evidence for a many-to-one mapping of form to function. Journal of Evolutionary Biology 31: 665-674 DOI: https://doi.org/10.1111/jeb.13251.
3. **Blanke**, A., Schmitz, H., Dutel, H., Patera, A., Fagan, M. 2017. Form function relationships in dragonfly mandibles under an evolutionary perspective. Journal of The Royal Society Interface 14: 20161038. [3.5] http://dx.doi.org/10.1098/rsif.2016.1038
4. **Blanke**, A., Watson, P.J., Holbrey, R., Fagan, M.J. 2017. Computational biomechanics changes our view on insect head evolution. Proceedings of the Royal Society B 284: 20162412. https://doi.org/10.1098/rspb.2016.2412
5. David, S., Funken, J., Potthast, W., **Blanke**, A. 2016. Muskuloskeletal modeling under an evolutionary perspective: Deciphering the role of single muscle regions in closely related insects. Journal of The Royal Society Interface 13: 20160675. http://dx.doi.org/10.1098/rsif.2016.0675

Five other relevant publications

1. **Blanke**, A. 2018. Analysis of modularity and integration suggests evolution of dragonfly wing venation mainly in response to functional demands. Journal of The Royal Society Interface. DOI: https://doi.org/10.1098/rsif.2018.0277.
2. David, S., Funken, J., Potthast, W., **Blanke**, A. 2016. Musculoskeletal modelling of the dragonfly mandible system as an aid to understanding the role of single muscles in an evolutionary context. Journal of Experimental Biology 216: 1041-1049. [3.2] https://doi.org/10.1242/jeb.132399
3. Misof B.; Liu S.; Meusemann K.; Peters R.S.; Donath A.; Mayer C.; Frandsen P.B.; Ware J.; Flouri T.; Beutel R.G.; Niehuis O.; Petersen M.; Izquierdo-Carrasco F.; Wappler T.; Rust J.; **Blanke**, A. et.al. 2014. Phylogenomics resolves the timing and pattern of insect evolution. Science 346: 763-767. http://dx.doi.org/10.1126/science.1257570

4. **Blanke**, A., Greve, C., Wipfler, B., Beutel, R.G., Holland, B., Misof, B. 2013. The identification of concerted convergence in insect heads corroborates Palaeoptera. Systematic Biology 62: 231-249. http://dx.doi.org/10.1093/sysbio/sys091
5. R. Mokso, L. Quaroni, F. Marone, S. Irvine, J. Vila-Comamala, A. **Blanke**, M. Stampanoni. 2012 X-ray mosaic nanotomography of large microorganisms. Journal of Structural Biology 177: 233-238. http://dx.doi.org/10.1016/j.jsb.2011.12.014

D. Synergistic Activities

- Chair of the 62nd Phylogenetic Symposium in 2020 ("Macroevolutionary dynamics in time and space")
- Organisation of eight workshops since 2014 about quantitative morphology and biomechanics.
- Associate Editor of the Journal of Zoological Systematics and Evolutionary Research (IF: 3.2) (2016-Present)
- Served as ERC, BBSRC, NERC, SNSF, and ANR Peer Reviewer (2016-Present)
- Served as reviewer for 20+ indexed journals (e.g. Current Biology, Science Advances, PLOS Computational Biology)

Biographical Sketches of Other Senior USA Personnel

Alexander J. Hunt

Address: Maseeh College of Engineering and Computer Science, PO Box 751 ME, Portland, OR 97207
Phone: 1-503-725-4265
E-mail: ajh26@pdx.edu

Professional Preparation:

Case Western Reserve University	Cleveland, OH	Mechanical Engineering	B.S. May 2009
Case Western Reserve University	Cleveland, OH	Mechanical Engineering	M.S. May 2010
Case Western Reserve University	Cleveland, OH	Mechanical Engineering	Ph.D. Jan. 2016
Case Western Reserve University	Cleveland, OH	Biomedical Engineering	Oct. 2015-July 2016

Appointments

Assistant Professor September 2016 – Present
Portland State University; Portland, OR
Mechanical and Materials Engineering Department

Postdoctoral Fellow October 2015 – July 2016
Case Western Reserve University; Cleveland, Ohio
Research at Louis Stokes VA Medical Center, Cleveland, Ohio

Representative products most related to DCSD

1. B. Bolen and A. J. Hunt, "Determination of Artificial Muscle Placement for Biomimetic Humanoid Robot Legs," in Biomimetic and Biohybrid Systems, Nara, Japan, 2019.
2. C. Scharzenberger, J. Mendoza, and A. J. Hunt, "Design of a Canine Inspired Quadruped Robot as a Platform for Synthetic Neural Network Control," in Biomimetic and Biohybrid Systems, Nara, Japan, 2019.
3. Alexander Hunt, Nicholas Szczecinski, and Roger Quinn. Development and Training of a Neural Controller for Hind Leg Walking in a Dog Robot. Frontiers in Neurorobotics, 11, 2017
4. Alexander Hunt, Manuela Schmidt, Martin Fischer, and Roger Quinn. A biologically based neural system coordinates the joints and legs of a tetrapod. Bioinspiration & Biomimetics, 10(5):055004, 2015
5. Alexander J. Hunt, Nicholas S. Szczecinski, Emanuel Andrada, Martin Fischer, and Roger D. Quinn. Using Animal Data and Neural Dynamics to Reverse Engineer a Neuromechanical Rat Model. In Stuart P. Wilson, Paul F. M. J. Verschure, Anna Mura, and Tony J. Prescott, editors, Biomimetic and Biohybrid Systems, number 9222 in Lecture Notes in Computer Science, pages 211–222. Springer International Publishing, July 2015

Biographical Sketches of Other Senior USA Personnel

Additional projects

1. W. W. Hilts, N. S. Szczecinski, R. D. Quinn, and A. J. Hunt, “A Dynamic Neural Network Designed Using Analytical Methods Produces Dynamic Control Properties Similar to an Analogous Classical Controller,” IEEE Control Systems Letters, vol. 3, no. 2, pp. 320–325, Oct. 2018.
2. A Steele, A Hunt, and A Etoundi, “Biomimetic Knee Design to Improve Joint Torque and Life for Bipedal Robotics,” presented at the Towards Autonomous Robotic Systems, Bristol, UK, 2018.
3. Alexander J. Hunt, Brooke M. Odle, Lisa M. Lombardo, Musa L. Audu, and Ronald J. Triolo. Reactive stepping with functional neuromuscular stimulation in response to forward-directed perturbations. Journal of NeuroEngineering and Rehabilitation, 14:54, June 2017
4. A. J. Hunt, R. J. Bachmann, R. R. Murphy, and R. D. Quinn. A rapidly reconfigurable robot for assistance in urban search and rescue. In 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems, pages 209–214, September 2011
5. Deng, Kaiyu, Nicholas S Szczecinski, Dirk Arnold, Emanuel Andrada, Martin Fischer, Roger D Quinn, and Alexander J Hunt. “Neuromechanical Model of Rat Hind Limb Walking with Two-Layer CPGs.” *Biomimetics* 2019, 4, (1).

Selected Synergistic Activities

1. **Mentoring:** Undergraduate Research and Mentoring Program Mentor, REU Mentor.
2. **Professional Membership:** American Society of Mechanical Engineers (2010-Present). Society for Neurosciences (2018).
3. **Teaching:** Developed and teach a course in robotics for the Department of Mechanical and Materials Engineering at Portland State University.
4. **University service:** Member of curriculum committee; hosts regular lab tours for prospective students and community members.
5. **Community service:** Regular presentations to FIRST robotics teams.

Biographical Sketches of Other Senior USA Personnel

Marie-Claude Perreault, PhD
Assistant Professor of Physiology
Department of Physiology, Faculty of Medicine
Emory University
Atlanta, Georgia 30322-1047
m-c.perreault@emory.edu

A. Professional Preparation

Institution	Location	Major	Degree &Year
University of Montréal	Québec, Canada	Physique	B.Sc., 1986
Université de Montréal	Québec, Canada	Neuroscience (Anatomy)	M.Sc., 1987
Université de Montréal	Québec, Canada	Neuroscience (Physiology)	Ph.D., 1993
University of Manitoba	Manitoba, Canada	Neurophysiology	1996

B. Appointments

Primary

2011-present	Assistant Professor, Physiology, Emory University, USA
2009-2011	Assistant Professor, National Centre for Stem Cell Research, Norway
1999-2009	Assistant Professor, Physiology, University of Oslo, Norway
1996-1999	Research Associate Professor, Physiology, University of Copenhagen, Denmark

Secondary

2015-present	Adjunct Faculty, Wallace H. Coulter Dept. of Biomedical Engineering, GT, USA

C. Products

Five most relevant publications (* denotes trainee):

1. **Perreault M-C** and Giorgi A (2019) Diversity of reticulospinal systems in mammals. *Current Opinion in Physiology* 8:161-169. NIHMS 1523777 (PMID in process)
2. Jean-Xavier C and **Perreault M-C** (2018) Influence of Brain Stem on Axial and Hindlimb Spinal Locomotor Rhythm Generating Circuits of the Neonatal Mouse. *Frontiers in Neuroscience*1 2:53. doi: 10.3389/fnins.2018.00053. PMID: 29479302.
3. Sivertsen MS*, Glover JC, **Perreault MC** (2014) Organization of pontine reticulospinal inputs to motoneurons controlling axial and limb muscles in the neonatal mouse. *Journal of Neurophysiology* 112:1628-1643. PMID: 24944221
4. Szokol K*, Glover JC and **Perreault M-C** (2011) Organization of functional synaptic connections between medullary reticulospinal neurons and lumbar descending commissural interneurons in the neonatal mouse. *Journal of Neuroscience* 31:4731-4742. PMID: 21430172

5. Szokol K*, Glover JC, **Perreault M-C** (2008) Differential origin of reticulospinal drive to motoneurons innervating trunk and hindlimb muscles in the mouse revealed by optical recording. *Journal of Physiology* 586:5259-5276. PMID: 18772205

Five other relevant publications

1. Nielsen JB, Conway BA, Halliday DM, **Perreault M-C,** Hultborn H (2005) Organization of common synaptic drive to motoneurones during fictive locomotion in the spinal cat. *Journal of Physiology* 569:291-304. PMID: 16166163
2. **Perreault M-C** (2002) Motoneurons have different membrane resistance during fictive scratching and weight support. *Journal of Neuroscience* 22:8259-65. PMID: 12223580
3. **Perreault M-C**, Enriquez-Denton M, Hultborn H (1999) Proprioceptive control of extensor activity during fictive scratching and weight support compared to fictive locomotion. *Journal of Neuroscience* 19:10966-76. PMID: 10594077
4. Hultborn H, Conway BA, Gossard JP, Brownstone R, Fedirchuk B, Schomburg ED, Enríquez-Denton M, **Perreault M-C** (1998) How do we approach the locomotor network in the mammalian spinal cord? *Annuals New York Academy of Science* 860:70-82. PMID: 9928302
5. **Perreault M-C,** Angel MJ, Guertin P, McCrea DA (1995) Effects of stimulation of hindlimb flexor group II afferents during fictive locomotion in the cat. *Journal of Physiology* 487:211-20. PMID: 7473250

D. Synergistic Activities

- International Summer School Teaching Federation of European Neuroscience Societies (FENS), Integrative Human Physiology-Sensorimotor Control (University of Copenhagen, Denmark) - 1999; Computational Models of Cellular Signaling in the Nervous System (Kristineberg Marine Research Station- Sweden) - 2006
- Atlanta Chapter of the Society for Neuroscience , For promotion of research and public understanding of the brain and nervous system - 2013-2015
- Mentoring of Undergraduate students (8) and High School Students (2), I teach students about neuroscience research through small lab projects or implementation of individual study programs - 2013-present
- Grant Review Service, Sensorimotor Integration (SMI) Study Section, NIH/NINDS-2014, Centers of Biomedical Research Excellence (COBRE), NIH/NIGMS- Puerto Rico Center for Neural Plasticity -2015, Conquer Paralysis Now (CPN), Sam Schmidt Foundation - 2014-2017
- Guest Academic Editor PLOS Biology- 2017-present

Biographical Sketches of Other Senior USA Personnel

Victoria A. Webster-Wood, PhD

Assistant Professor
Department of Mechanical Engineering
Department of Biomedical Engineering, by courtesy
Carnegie Mellon University
Pittsburgh, PA 15116
vwebster@andrew.cmu.edu

A. Professional Preparation

Institution	Location	Major	Degree &Year
Case Western Reserve University	Cleveland, Ohio	Mechanical Engineering	B.S., 2012
			M.S., 2013
			Ph.D., 2017

B. Appointments

2018-Present	Assistant Professor of Mechanical Engineering, Carnegie Mellon University
2018-Present	Assistant Professor of Biomedical Engineering, by courtesy, CMU

C. Products

Five most relevant publications:

1. **Webster-Wood, V.**, Akkus, O., Gurkan, U., Chiel, H., Quinn, R. "Organismal Engineering: Towards a Robotic Taxonomic Key for Devices Using Organic Materials". Science Robotics. 2(12). November 2018.
2. **Webster, V.**, Chapin, K., Hawley, E., Patel, J., Akkus O., Chiel, H., Quinn, R. "*Aplysia californica* as a Novel Source of Material for Biohybrid Robots and Organic Machines". in Biomimetic and Biohybrid Systems: Proceedings of Living Machines 2016. July 18-22, 2016 Edinburgh, Scotland. 2nd Place in Presentation Competition.
3. **Webster, V.**, Young, F., Patel, J., Scariano, G., Akkus, O., Gurkan, U., Chiel, H., Quinn, R. "3D-printed Biohybrid Robots Powered by Neuromuscular Tissue Circuits from *Aplysia californica*". in Biomimetic and Biohybrid Systems: Proceedings of Living Machines 2017. July 25-28, 2017 San Francisco, USA.
4. **Webster, V.**, Leibach, R., Hunt, A., Bachmann, R., Quinn, R. "Design and Control of a Tunable Compliance Actuator". in Biomimetic and Biohybrid Systems: Proceedings of Living Machines 2014. July 30-August 1. 2014. Milan, Italy. pp 244-255.
5. **Webster, V.**, Lonsberry, A., Horchler, A., Shaw, K., Chiel, H., Quinn, R. "A Segmental Mobile Robot with Active Tensegrity Bending and Noise-driven Oscillators". AIM 2013. Wollongong, Australia. 2013.

Four other relevant publications

1. **Webster, V.**, Szczecinski, N., Tietz, B., Daltorio, K., Porr, D., Richards, J., Ritzmann, R., Quinn, R. "Barrier Navigating and Shelter Seeking Robot Inspired by Cockroach Behavior". CLAWAR 2012, Baltimore, MD. 2012.

2. Daltorio, K., Tietz, B., Bender, J., **Webster, V.**, Szczecinski, N., Branicky, M., Ritzmann, R., Quinn, R. "A Stochastic Algorithm for Explorative Goal Seeking Extracted from Cockroach Walking Data". ICRA 2012. pp 2261-2268. May 2012.
3. **Webster VA,** Chapin KJ, Akkus O, Chiel HJ and Quinn RD (2016). *Aplysia californica* as a source of actuators, scaffolds, and controllers for the development of biohybrid robots and living machines. Neuroscience 2016. November 12-16, 2016. San Diego, USA.
4. Daltorio, K., Tietz, B., Bender, J., **Webster, V.**, Szczecinski, N., Branicky, M., Ritzmann, R., Quinn, R. "A model of exploration and goal-seeking in the cockroach Blaberus discoidalis". Adaptive Behavior. 21(5). 404-420. Oct 2012.

D. Synergistic Activities

- Undergraduate course “Gadgetry: Sensors, Actuators, and Processors” (2018 – Present)
- Undergraduate Outreach: Host lab for undergraduate researchers in robotics. Currently supporting a total of 8 undergraduate students including four women, two of whom are Hispanic and two Hispanic men.
- 2015 Best Poster Award, Living Machines Conference, Barcelona
- CWRU MAE Professional Service Award
- NIH Ruth L. Kirschstein NRSA Postdoctoral Fellow, 2017-2018

Pursuant to PAPPG Chapter II.C.1.e., each PI, co-PI, and other senior project personnel identified on a proposal must provide collaborator and other affiliations information to help NSF identify appropriate reviewers.(v.4/21/2017)

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc.
Do not upload .pdf.

There are five tables:
A: Your Name & Affiliation(s);
B: PhD Advisors/Advisees (all);
C: Collaborators;
D: Co-Editors;
E: Relationships

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional) to disambiguate common names.

Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and abbreviate, where necessary, to make the data fit.

To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
"Last active" dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.

Table A: List your Last Name, First Name, Middle Initial, and organizational affiliation (including considered affiliation) in the last 12 months.

A	Your Name:	Your Organizational Affiliation(s), last 12 m	Last Active Date
	Hunt, Alexander J	Portland State University	

Table B: List names as Last Name, First Name, Middle Initial, and provide organizational affiliations, if known, for the following.

G: Your PhD Advisor(s)
T: All your PhD Thesis Advisees
P: Your Graduate Advisors

to disambiguate common names

B	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:	Quinn, Roger D	Caese Western Reserve University	Mechanical and Aerospace Eng.

Table C: List names as Last Name, First Name, Middle Initial, and provide organizational affiliations, if known, for the following.

A: Co-authors on any book, article, report, abstract or paper (with collaboration in last 48 months; publication date may be later).

C: Collaborators on projects, such as funded grants, graduate research or others (in last 48 months).

to disambiguate common names

C	Name:	Organizational Affiliation	Optional (email, Department)	Last Active

C:	Andrada, Emanuel	Fredrich Schiller University of Jena	emanuel.andrada@uni-jena.de	5/1/19
C:	Arnold, Dirk	Fredrich Schiller University of Jena	d.arnold@uni-jena.de	5/1/19
A:	Audu, Musa	Case Western Reserve University	Biomedical Engineering	6/1/17
A:	Bracun, Drago	University of Ljubljana	Mechanical Engineering	7/1/18
A:	Deng, Kaiyu	Case Western Reserve University	Mechanical and Aerospace Eng.	5/1/19
A:	Etoundi, Appolonaire	University of West England	Engineering Design and Mathematics	5/1/19
C:	Fischer, Martin	Fredrich Schiller University of Jena	Martin.Fischer@uni-jena.de	5/1/19
A:	Hilts, Wade	Oregon Health and Science University	Biomedical Engineering	11/1/18
C:	Horak, Fay	Oregon Health and Science University	Neurology	5/1/19
A:	Lombardo, Lisa	Cleveland Stokes VA Hospital	APT Center	6/1/17
A:	Odle, Brooke	Case Western Reserve University	Biomedical Engineering	6/1/17
C:	Peterka, Robert	Oregon Health and Science University	Biomedical Engineering	5/1/19
A:	Quinn, Roger D	Case Western Reserve University	Mechanical and Aerospace Eng.	5/1/19
C:	Rode, Christian	Fredrich Schiller University of Jena	christian.rode@uni-jena.de	5/1/19
A:	Skulj, Gasper	University of Ljubljana	Mechanical Engineering	7/1/18
A:	Steele, Alexander	Portland State University	Mechanical and Materials Engineerin	5/1/19
A:	Szczecinski, Nicholas	Case Western Reserve University	Mechanical and Aerospace Eng.	5/1/19
A:	Triolo, Ronald	Case Western Reserve University	Biomedical Engineering	6/1/17
C:	Wildau, Julia	Fredrich Schiller University of Jena	Julia.Wildau@gmx.de	5/1/19
A:	Young, Fletcher	Case Western Reserve University	Mechanical and Aerospace Eng.	5/1/19

Table D: List editorial board, editor-in-chief and co-editors with whom you interact. An editor-in-chief should list

B: Editorial board: Name(s) of editor-in-chief and journal (in past 24 months).

E: Other Co-Editors of journals or collections with whom you directly interacted (in past 24 months).

to disambiguate common names

D	Name:	Organizational Affiliation	Journal/Collection	Last Active

Table E: List persons for whom a personal, family, or business relationship would otherwise preclude their service

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

D	Name:	Organizational Affiliation	Optional (email, Department)	Last Active

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **The individual's Ph.D. advisors; and**
- **All of the individual's Ph.D. thesis advisees.**

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
- **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**
- **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
- **Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and**
- **Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.**

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
“Last Active Date” and “Last Active” columns may be left blank for ongoing or current affiliations.

Table 1: List the individual’s last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 r	Last Active Date
	Perreault, Marie-Claude	Emory University	
		Gerogia Tech (adjunct)	

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:	Raastad, Morten	Family		

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual’s Ph.D. advisors; and
T: All of the individual’s Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:			

T:	Szokol, Karolina	Advisor, Research Council, Norway	
T:	Kasumacic, N	Lecturer, Sonas High School, Norway	
T:	Sivertsen, MS	Medical Doctor, Ulleval Hospital, Norway	

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and

C: Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

to disambiguate common names

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active
A:	Walter, Gary C	University of Arizona, USA		
A:	Brandon, LaPallo	Teva Pharmaceuticals, USA		
A:	Jean-Xavier, Celine	University of Calgary, Canada		
A:	Giorgi, Andrea	Emory University, USA		
A:	Glover, Joel C	University of Oslo, Norway		
A:	Lambert, Francois M	Université de Bordeaux, France		
A:	Coulon, Patrice	CNRS and Aix Marseille Université, France		
A:	Bras, Helen	CNRS and Aix Marseille Université, France		
A:	Vinal, Laurent	n/a		
C:				

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

E: Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:	Gasque, Gabriel		PLOS Biology	3/25/19
E:				

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

Please note that some information requested in prior versions of the PAPPG is no longer requested. THIS IS PURPOSEFUL AND WE NO LONGER REQUIRE THIS INFORMATION TO BE REPORTED. Certain relationships will be reported in other sections (i.e., the names of postdoctoral scholar sponsors should not be reported, however if the individual collaborated on research with their postdoctoral scholar sponsor, then they would be reported as a collaborator). The information in the tables is not required to be sorted, alphabetically or otherwise.

There are five separate categories of information which correspond to the five tables in the COA template:

COA template Table 1:
List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

COA template Table 2:
List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

COA template Table 3:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
• The individual's Ph.D. advisors; and
• All of the individual's Ph.D. thesis advisees.

COA template Table 4:
List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:
• Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and
• Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

COA template Table 5:
List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.
• Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and
• Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

The template has been developed to be fillable, however, the content and format requirements must not be altered by the user. This template must be saved in .xlsx or .xls format, and directly uploaded into FastLane as a Collaborators and Other Affiliations Single Copy Document. Using the .xlsx or .xls format will enable preservation of searchable text that otherwise would be lost. It is therefore imperative that this document be uploaded in .xlsx or .xls only. Uploading a document in any format other than .xlsx or .xls may delay the timely processing and review of the proposal.

This information is used to manage reviewer selection. See Exhibit II-2 for additional information on potential reviewer conflicts.

1 Note that graduate advisors are no longer required to be reported.
2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
“Last Active Date” and “Last Active” columns may be left blank for ongoing or current affiliations.

Table 1: List the individual’s last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 r	Last Active Date
	Webster-Wood, Victoria A	Carnegie Mellon University	current
		Case Western Reserve University (postdoc)	6/1/2018

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:	Webster, Robert, B.	family	Texas A&M, Nuclear Engineering	present

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual’s Ph.D. advisors; and
T: All of the individual’s Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:	Quinn, Roger, D.	Case Western Reserve University	

G:	Akkus, Ozan	Case Western Reserve University	
G:	Chiel, Hillel, J.	Case Western Reserve University	
T:	Sun, Wenhuan	Carnegie Mellon University	
T:	Dai, Kevin	Carnegie Mellon University	

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: **Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and**

C: **Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.**

to disambiguate common names

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active
C:	Quinn, Roger, D.	Case Western Reserve University		current
C:	Akkus, Ozan	Case Western Reserve University		current
C:	Chiel, Hillel, J.	Case Western Reserve University		current
C:	Farimani, Amir	Carnegie Mellon University		current
C:	Zhang, Jessica	Carnegie Mellon University		current
C:	Feinberg, Adam	Carnegie Mellon University		current
C:	Atkeson, Christopher	Carnegie Mellon University		current
C:	Yuan, Wenzhen	Carnegie Mellon University		current
C:	Feng, Chen	New York University		current
A:	Gurkan, Umut	Case Western Reserve University		
A:	Abraham, Zachary	Case Western Reserve University		
A:	Hawley, Emma	Case Western Reserve University		
A:	Hayosh, Daniel	Case Western Reserve University		
A:	Young, Fletcher	Case Western Reserve University		
A:	Patel, Jill	Case Western Reserve University		
A:	Scariano, Gabrielle	Case Western Reserve University		
A:	Guerra Nieto, Santiago	Case Western Reserve University		
A:	Grosberg, Anna	University of California - Irvine		
A:	McClellan, Phillip	Case Western Reserve University		
A:	Mbimba, Thomas			
A:	Chapin, Katherine	Progressive Insurance		
A:	Leibach, Ron	Case Western Reserve University		
A:	Hunt, Alexander	Portland State University		
A:	Bachmann, Richard	Case Western Reserve University		
A:	Suzuki, Takayuki	Case Western Reserve University		

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.

B: **Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and**

E: **Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.**

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active