Washington and Lee Law Review

Volume 73 | Issue 2 Article 9

Spring 4-1-2016

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Recommended Citation
Loren Peck, *How Sound Is the Science? Applying Daubert to Biomechanical Experts' Injury Causation Opinions*, 73 Wash. & Lee L. Rev. 1063 (2016), http://scholarlycommons.law.wlu.edu/wlulr/vol73/iss2/9

How Sound Is the Science? Applying *Daubert* to Biomechanical Experts' Injury Causation Opinions

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I. Introduction

Melinda Crandall was stopped at a freeway metering light when she was rear-ended by a teenage driver.[1] At forty-five, Mrs.

1. Plaintiffs' *Daubert* Motion Re: Expert Witness Testimony of Wilson C.

Crandall was a recovering quadriplegic with two cervical fusions from prior injuries.[2] Mrs. Crandall was in immediate distress, and paramedics rushed her to a hospital.[3] Beginning the day of the accident, Mrs. Crandall complained of new pain in her head and neck that made her nauseous and caused severe and frequent vomiting.[4] Approximately ten months after the accident, a tear in Mrs. Crandall's carotid artery led to a stroke, which caused permanent cognitive deficits.[5]

Mrs. Crandall's automobile insurer hired a neurologist, Dr. Alan Goldman, to decide whether the tear in the artery could have been caused by the collision.[6] Dr. Goldman reported that the accident had worsened Mrs. Crandall's head and neck pain, which had caused vomiting, which in turn probably caused the artery to tear.[7] Dr. Goldman attributed 60% of Mrs. Crandall's headaches to the rear-end accident and 40% to preexisting injuries.[8] Based on that report and similar opinions from Mrs. Crandall's treating doctors, the Crandalls submitted a claim for medical expenses under their auto insurance policy.[9] The insurer denied their claim.[10]

Melinda filed a lawsuit. In response, her insurance company hired experts, including a biomechanical engineer, Wilson C. Hayes, Ph.D.[11] Dr. Hayes used accident reconstruction

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Hayes, Ph.D. and Incorporated Memorandum in Support at 2, Crandall v. Am. Family Mut. Ins., No. 2:11-CV-00497 (D. Utah Mar. 4, 2013), 2013 WL 9850959 [hereinafter Plaintiffs' *Daubert* Motion]. The speed of the teenager's vehicle was later estimated to be five miles per hour or less. *Id.*

2. *Id.*

3. *Id.*

4. *Id.*

5. Crandall v. Am. Family Mut. Ins. Co., No. 2:11-CV-497-RJS, 2013 WL 5819283, at *1 (D. Utah Oct. 29, 2013).

6. Plaintiffs' *Daubert* Motion, *supra* note 1, at 2–3.

7. *Id.*

8. *Id.*

9. *Crandall*, 2013 WL 5819283, at *1. The Crandall's American Family auto insurance policy promised $100,000 for medical expenses, with an additional $1,000,000 available in an umbrella policy. At the time the Crandalls submitted the claim, a life care planner had estimated that Mrs. Crandall's medical expenses would exceed $2,000,000. *Id.*

10. *Id.*

11. Plaintiffs' *Daubert* Motion, *supra* note 1, at xv–xix.

techniques and computer software to simulate forces in the accident.[12] Dr. Hayes concluded that the collision was incapable of causing either the arterial injury or any aggravation of prior injuries because the forces were comparable to "activities of daily living," such as skipping rope, running and abruptly stopping, and hopping.[13] Melinda moved to exclude Dr. Hayes's opinions under *Daubert*.[14] The federal district court judge allowed some of Dr. Hayes's opinions, but excluded any opinions regarding whether or not the accident was the cause of Mrs. Crandall's injuries. Referring to the sparse case law applying *Daubert* to biomechanical engineers' testimony, the judge observed that "there are cases all over the map on this issue."[15]

Biomechanical engineers' entry into personal injury litigation has sparked debate about scientists' role in personal injury litigation.[16] Medical experts have a longstanding monopoly on injury causation testimony, but some now argue that biomechanical engineers are even more qualified to determine the cause of traumatic injuries.[17] Biomechanical experts use

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12. Memorandum in Opposition to Plaintiffs' *Daubert* Motion Re: Expert Witness Testimony of Wilson C. Hayes, Ph.D. and Incorporated Memorandum in Support, Exhibit C at 2, 19, Crandall v. Am. Family Mut. Ins., No. 2:11-CV-00497 (D. Utah Mar. 4, 2013) [hereinafter Memorandum in Opposition to Plaintiffs' *Daubert* Motion]. Dr. Hayes's testimony regarding the force necessary to cause arterial injury contradicted the testimony of a neurologist, neurosurgeon, and a neuro-interventional surgeon. *See* Plaintiffs' *Daubert* Motion, *supra* note 1, at xv–xix (quoting five medical experts as testifying that minor, trivial trauma can cause carotid artery dissection).

13. Memorandum in Opposition to Plaintiffs' *Daubert* Motion, *supra* note 12, Exhibit C at 2, 19. There are many cases like *Crandall v. American Family Mutual Insurance*. Auto insurers have been hiring biomechanical experts with increasing frequency after denying a claim. *See, e.g.*, Mason v. Rizzi, 89 A.3d 32, 34 (Del. 2004) (setting out nearly identical facts and proffered expert testimony); Eskin v. Carden, 842 A.2d 1222, 1226–27 (Del. 2004) (same); *see also See* Donna L. Burden et al., *Biomechanical Engineering Testimony: Legitimate Expert Analysis or Junk Science?*, 47 DRI DEF. 21, 21 (2005) ("Today, biomechanical engineers are being used in a variety of cases to address the forces involved in an accident (especially low-impact cases) and to determine whether the accident could have caused a plaintiff's injuries.").

14. Transcript of Record at 10, Crandall v. Am. Family Mut. Ins., No. 2:11-CV-00497 (D. Utah May 30, 2014), ECF No. 129.

15. *Id.*

16. *See id.* (collecting arguments made in courts regarding the qualifications of biomechanical engineers).

17. *See* Memorandum in Opposition to Plaintiffs' *Daubert* Motion, *supra*

computer simulations and physics in a "high technology approach to causation" that may appear more credible than "the more traditional but low-technology clinical approach."[18] Trial courts applying *Daubert* to biomechanical experts' qualifications and methodologies have reached contradictory results, often providing little explanation for their decisions.[19]

This Note applies the *Daubert* standard to typical biomechanical engineer qualifications and methodologies. This Note argues that biomechanical expert testimony regarding injury causation should be limited due to engineers' inability to adapt generic data to individual plaintiffs. Part II gives a brief explanation of biomechanical engineering. Part III provides an overview of the law governing the admission of expert testimony. Part IV applies *Daubert*'s qualifications prong and argues that biomechanical engineers who lack medical expertise should only be allowed to make general statements about injury causation. Part V applies *Daubert*'s reliability prong to typical forensic biomechanical methodologies and argues that extrapolation from population-based studies is not a reliable basis for specific causation opinions. Part V also argues that some opinions regarding general aspects of injury causation may be inadmissible due to the limitations of biomechanical research. Part VI applies *Daubert's* relevance and helpfulness prong and argues that general causation opinions are not always relevant,

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note 12, Exhibit 1 at 9 (quoting a prominent biomechanical expert's affidavit that "[i]n most instances it is the biomechanical expert rather than the medical practitioner who is most qualified, on the basis of education, training and experience, to express opinions on issues of injury causation"); Layssard v. United States, No. 06-0352, 2007 WL 4144936, at *7–8 (W.D. La. Nov. 20, 2007) ("In essence, [the biomechanical engineer] . . . refuses to defer to the opinion of a medical doctor because the medical doctor presumably does not have his own engineering knowledge."); David L. Gushue et al., *Low Speed Impacts: Effective Use of Biomedical Engineers*, 53 DRI DEF. 18, 18 (arguing that medical doctors "lack information, expertise, and a sufficient technical basis to evaluate the nature of the collision environment which is necessary to provide an opinion regarding injury causation").

18. Michael D. Freeman & Sean S. Kohles, *An Evaluation of Applied Biomechanics as an Adjunct to Systematic Specific Causation in Forensic Medicine*, 161 WIEN MED WOCHENSCHR 458, 458 (2011) [hereinafter Freeman & Kohles, *Evaluation of Applied Biomechanics*].

19. *See infra* note 111 and accompanying text (describing contradictory outcomes).

especially when the plaintiff's body is unlike those of test subjects in the biomechanical literature. Part VII offers a summary and proposes a roadmap for applying the *Daubert* standard to biomechanical expert opinions in personal injury cases.

II. Background

Biomechanics exists at the crossroads of engineering and biology,[20] focusing on how mechanical energy affects human tissue.[21] Biomechanical engineering is a branch of biomedical engineering, which falls within the broader field of bioengineering.[22] Biomechanical research has contributed to our understanding of motor vehicle and aircraft crashworthiness,[23] childbirth,[24] slip-and-fall accidents,[25] child

20. *See* Robert M. Arthur, *"Bioengineering," a Definition*, 14 BIOSCIENCE 29, 29 (1964) ("Bioengineering is presently being practiced by engineers who have taken an interest in biology . . . .").

21. *See, e.g.*, Garner v. Baird, 910 N.Y.S.2d 762, 762 (N.Y. Civ. Ct. 2010) (defining biomechanics as "the application of physics and mechanical engineering to the human body"); Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 458 ("Biomechanics may be simply defined as the study of the effect of mechanical energy on biological tissue."); Y.C. Fung, *Biomechanics, Its Scope, History and Some Problems of Continuum Mechanics in Physiology*, 21 APPLIED MECHANICS REV. 1, 28 (1968) ("[B]iomechanics is mechanics applied to biology.").

22. *See* Fung, *supra* note 21, at 29 fig.1 (listing biomechanics and bioastronautics as part of the broader field of biomedics).

23. *See id.* at 399 (discussing the relationship between biomechanical engineers and the National Highway Safety Bureau, which developed a set of standards controlling the performance of cars in terms of their crashworthiness); *see also* NAT'L TRANSP. SAFETY BD., HIGHWAY SPECIAL INVESTIGATION REPORT: BUS CRASHWORTHINESS 15 (Sept. 21, 1999) (discussing the benefit of computer simulations created by biomechanical engineers of a school bus roll-over as a tool "to evaluate specific mechanical and biomechanical issues for similar types of accidents"); Jeffrey Augenstein & Kennerly Digges, *Performance of Advanced Air Bags Based on Data William Lehman Injury Research Center and New NASS PSUs*, 47TH ANN. PROC. ASS'N ADVANCEMENT AUTOMOTIVE MED. 1, 1–2 (2003) (discussing methods used for gathering data from patients suffering traumatic injuries and making connections to vehicle safety design).

24. *See* James A. Ashton-Miller & John O.L. DeLancey, *On the Biomechanics of Vaginal Birth and Common Sequelae*, 11 ANN. REV. BIOMECHANICAL ENGINEERING 163, 173 (2009) (discussing the biomechanics of childbirth and developing a biomechanical model for anterior vaginal wall prolapse).

25. *See* Wojciech Wach & Jan Unarski, *Fall From Height in a Stairwell—*

abuse,[26] athletics,[27] and even the motor development of infants and children.[28] While a general interest in the connection between biology and physics is nothing new, the field of biomechanics has only received widespread recognition in recent decades.[29]

A. Biomechanics in Litigation

Outside of litigation, biomechanical research focuses in several main areas, including: (i) how and why injuries occur in populations; (ii) which of two or more competing injury mechanisms was most likely to have caused an injury; and (iii) how an injury might have been mitigated by safety countermeasures.[30] Biomechanical analyses have been helpful as an adjunct to medical investigations seeking to discover how an

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Mechanics and Simulation Analysis, 244 FORENSIC SCI. INT'L 136, 136 (2014) (describing the body of biomechanical research regarding falls from height as "extensive").

26. *See* Mary Clyde Pierce & Gina Bertocci, *Injury Biomechanics and Child Abuse*, 10 ANN. REV. BIOMECHANICAL ENGINEERING 85, 88 (2008) (discussing the role of biomechanical research in improving the accuracy of "differentiating child abuse from accidental trauma").

27. *See* Caroline F. Finch, Shahid Ullah & Andrew S. McIntosh, *Combining Epidemiology and Biomechanics in Sports Injury Prevention Research*, 41 SPORTS MED. 59, 65 (2011) ("Aetiological approaches towards studying sports injury, which aim to understand how and why injuries occur, need to be firmly planted in biomechanics.").

28. See A. J. "Knoek" van Soest & Annick Ledebt, *Towards a Broader Scope of Biomechanics in Developmental Studies: A Commentary on Jensen* (2005), 14 INFANT CHILD DEV. 513, 515–16 (2005) (applying biomechanical principles to explain universal sequence in motor milestones).

29. *See* Murray Mackay, *The Increasing Importance of the Biomechanics of Impact Trauma*, 32 SĀDHANĀ 397, 401–02 (2007) (discussing the rise of experimental impact biomechanics in the 1980s and 1990s).

30. *See* Michael D. Freeman & Sean S. Kohles, *Applications and Limitations of Forensic Biomechanics: A Bayesian Perspective*, 17 J. FORENSIC LEGAL MED. 67, 67 (2009) [hereinafter Freeman & Kohles, *Forensic Biomechanics*] (discussing differences between biomechanical research in the field and litigation-related analyses); *see also* R. Bahr & T. Krosshaug, *Understanding Injury Mechanisms: A Key Component of Preventing Injuries in Sport*, 9 BRIT. J. SPORTS MED. 324, 325 (2005) (stating that proper documentation of activities surrounding injury is a critical step in preventing future injuries and identifying potential mechanisms of injury).

injury occurred.[31] In addition, competent analyses of how injuries may be prevented have been routinely admitted in product liability litigation.[32] In personal litigation, however, biomechanical experts often focus less on *how* injuries may have occurred and more on *whether* injury occurred.[33]

Biomechanical engineers' first serious foray into litigation consulting came in 1979.[34] In the decade that followed, biomechanical engineers were predominantly hired in product liability litigation to offer opinions about design defects and alternative designs.[35] There were no notable court opinions applying *Daubert* to a biomechanic's injury causation opinion until 1997, when the Sixth Circuit decided *Smelser v. Norfolk Southern Railway*.[36] In *Smelser*, the Sixth Circuit held that a trial court should have limited biomechanical expert opinions to those regarding general aspects of causation.[37] The *Smelser*

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31. *See* June A. Ejlersen et al., *An Unusual Case of Sudden Unexpected Death: Postmortem Investigation and Biomechanical Analysis of the Cervical Spine*, 52 J. FORENSIC SCI. 462, 464 (2007) (describing a biomechanical analysis as an adjunct to a medical investigation of traumatology and cause of death).

32. *See infra* note 34 and accompanying text (collecting cases).

33. *See* Freeman & Kohles, *Forensic Biomechanics*, *supra* note 30, at 67 (noting that the goals of forensic biomechanical analyses are different than the goals of biomechanical analyses outside of litigation); *see also* Wilson C. Hayes et al., *Forensic Injury Biomechanics*, 2 ANN. REV. BIOMEDICAL ENGINEERING 55, 58 (2007) (arguing that biomechanical engineers can adapt and revise population-based criteria to apply to individuals).

34. *See* Lahocki v. Contee Sand & Gravel Co., 398 A.2d 490, 498 (Md. App. 1979) (admitting expert biomechanical engineer testimony regarding design safety in a defective manufacturing case involving a van rollover); *see also* Crump v. Universal Safety Equip. Co., 398 N.E.2d 188, 193 (Ill. App. 1979) (referencing biomechanical expert testimony regarding safety glasses in a product liability case).

35. *See* cases cited *supra* note 34 (collecting cases); *see also* Mannino v. Int'l Mfg. Co., 650 F.2d 846, 853 (6th Cir. 1981) (finding biomechanical expert testimony admissible regarding an allegedly defective child's car seat safety strap); Pineda v. L.A. Turf Club, Inc., 169 Cal. Rptr. 66, 68 (Cal. Ct. App. 1980) (noting a biomechanical consultant's trial testimony regarding an allegedly defective helmet); Cloud v. State, 420 So. 2d 1259, 1264 (La. Ct. App. 1982) (noting a biomechanical expert's opinion regarding the safety of stairs based on slope and tread but criticizing the expert's opinion regarding the cause of the plaintiff's fall); Sumnicht v. Toyota Motor Sales, Inc., 360 N.W.2d 2, 5 (Wis. 1984) (noting biomechanical expert testimony in a products liability case regarding the design of a passenger seat).

36. 105 F.3d 299 (6th Cir. 1997).

37. *See id.* at 305 (limiting biomechanical expert testimony to opinions

opinion is discussed in more detail in Part IV.B. Despite *Smelser*, the practice of retaining biomechanical experts in personal injury cases has become increasingly popular in the past twenty years.[38]

III. Rules Governing the Admissibility of Expert Testimony

This Part reviews the evolution of legal standards for expert testimony, beginning with the previously predominant test derived from *Frye v. United States*.[39] It then discusses the adoption of the Federal Rules of Evidence and the Supreme Court's interpretation of those rules in *Daubert v. Merrell Dow Pharmaceuticals*[40] as creating a new standard for expert testimony. Finally, it details the three prongs of the *Daubert* standard: expert qualifications, reliable methodology, and relevance.

A. The Frye *"General Acceptance" Test*

Between 1923 and 1993, the standard for evaluating expert testimony was rooted in *Frye*, a D.C. Circuit opinion. Under the *Frye* standard, the exclusive test for admissibility was whether an expert's methodology was "sufficiently established to have gained general acceptance in the particular field in which it belongs."[41] Some commentators criticized *Frye* as inflexible because it excluded novel scientific evidence that might have been reliable.[42]

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regarding general aspects of injury causation).

38. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 458 (noting that the use of forensic biomechanical methods to explain injury causation has been increasing over the past twenty years).

39. 293 F. 1013 (D.C. Cir. 1923).

40. 509 U.S. 579 (1993).

41. *Frye*, 293 F. at 1014.

42. *See, e.g.*, Bert Black, *A Unified Theory of Scientific Evidence*, 56 FORDHAM L. REV. 595, 628 (1988) (arguing that the *Frye* test was too incoherent to be applied effectively by the courts); Paul C. Giannelli, *The Admissibility of Novel Scientific Evidence:* Frye v. United States*, A Half-Century Later*, 80 COLUM. L. REV. 1197, 1207–08, 1223 (1980) (arguing that the *Frye* test was too vague and led to inconsistent results); DAVID H. DAYE ET AL., THE NEW WIGMORE, A TREATISE ON EVIDENCE: EXPERT EVIDENCE § 5.3.3 (2004) (noting that the *Frye*

In 1975, the Federal Rules of Evidence became effective, including Rule 702, which provided that "if scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise."[43] The adoption of Rule 702 "did not specifically preclude the use of the *Frye* standard to evaluate expert testimony,"[44] so "the effect of Rule 702 on the *Frye* standard was unclear."[45]

B. Daubert v. Merrell Dow Pharmaceuticals*: The Current Standard*

In 1993, the Supreme Court decided *Daubert* and clarified that the adoption of the Federal Rules of Evidence displaced the *Frye* test.[46] The Court explained that under the new standard, judges have a gatekeeping duty to assess whether expert qualifications and methodologies meet Rule 702's twin standards of relevance and reliability.[47] The Court suggested factors that would assist the judiciary in assessing the scientific validity of proffered expert evidence, including testability, peer review, rates of error, and general acceptance.[48] Subsequent cases and the

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opinion was unclear in its standard).

43. FED. R. EVID. 702.

44. Jennifer L. Groscup et al., *The Effects of* Daubert *on the Admissibility of Expert Testimony in State and Federal Criminal Cases*, 8 PSYCH. PUB. POL. & L. 339, 340 (2002).

45. Andrew Jurs & Scott De Vito, *The Stricter Standard: An Empirical Assessment of* Daubert*'s Effect on Civil Defendants*, 62 CATH. U.L. REV. 675, 685 (2013).

46. *See* Daubert v. Merrell Dow Pharms., 509 U.S. 579, 589 (1993) (discussing the *Frye* test and stating, "That austere standard, absent from, and incompatible with, the Federal Rules of Evidence, should not be applied in federal trials").

47. *See id.* at 592 ("Faced with a proffer of expert scientific testimony, then, the trial judge must determine at the outset, pursuant to Rule 104(a), whether the expert is proposing to testify to (1) scientific knowledge that (2) will assist the trier of fact to understand or determine a fact in issue.").

48. *See infra* notes 59–64 (outlining factors that have been suggested as helpful in assessing scientific testimony).

Advisory Committee notes to Rule 702 have elaborated on and added to these factors.[49]

Since *Daubert*, the Supreme Court has explained that "the Federal Rules of Evidence allow district courts to admit a somewhat broader range of scientific testimony than would have been admissible under *Frye*."[50] In *Kumho Tire Co. v. Carmichael*,[51] the Court stated that the intent of the *Daubert* standard was to ensure that any expert "employ[] in the courtroom the same level of intellectual rigor that characterizes the practice of an expert in the relevant field."[52] While a majority of states have adopted standards that are similar or identical to the federal *Daubert* standard, more than a dozen states and the District of Columbia continue to apply the *Frye* test, and a handful of states have developed different evidentiary standards.[53] This Note applies only the *Daubert* standard.

1. Expert Qualifications

Federal Rule of Evidence 702 requires that an expert be "qualified . . . by knowledge, skill, experience, training, or education."[54] This standard has been characterized as a "liberal one" but still requires "that the area of the witness's competence match the subject matter of the witness's testimony."[55]

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49. *See infra* notes 59–64 (same).

50. Gen. Elec. Co. v. Joiner, 522 U.S. 136, 142 (1997).

51. 526 U.S. 137 (1999).

52. *Id.* at 152.

53. *See generally* Alice B. Lustre, Annotation, *Post-*Daubert *Standards for Admissibility of Scientific and Other Expert Evidence in State Courts*, 90 A.L.R.5th 453 (2014) (comparing states' evidentiary standards for expert testimony).

54. FED. R. EVID. 702.

55. Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1351 (M.D. Ga. 2007) (citations omitted).

2. Reliable Methods

Rule 702 requires that experts testify based on "scientific, technical, or other specialized knowledge."[56] The Court in *Daubert* interpreted this to mean that the methods underlying an expert's opinions must be reliable.[57] To be reliable, the expert's reasoning or methodology must be "scientifically valid" and capable of being "properly applied to the facts in issue."[58] The assessment of reliability is a flexible one, with many potentially relevant considerations.[59] The Court in *Daubert* and its progeny identified some non-exclusive factors, including whether a theory or technique "can be (and has been) tested;"[60] "whether the theory or technique has been subjected to peer review and publication;"[61] "[w]hether . . . there is a high 'known or potential rate of error' and whether there are 'standards controlling the technique's operation.'"[62] "General acceptance" can also have a bearing on the inquiry.[63] The Advisory Committee's notes to Rule 702 add five additional considerations:

> (1) Whether the expert is proposing to testify about matters growing naturally and directly out of research he has conducted independent of the litigation, or whether he has developed his opinion expressly for purposes of testifying; (2) Whether the expert has unjustifiably extrapolated from an accepted premise to an unfounded conclusion; (3) Whether the expert has adequately accounted for obvious alternative explanations; (4) Whether the expert is being as careful as he would be in his regular professional work outside his paid litigation consulting; (5) Whether the field of expertise claimed

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56. FED. R. EVID. 702.

57. *See* Daubert v. Merrell Dow Pharms., 509 U.S. 579, 590 (1993) ("In short, the requirement that an expert's testimony pertain to 'scientific knowledge' establishes a standard of evidentiary reliability.").

58. *Id.* at 592–93.

59. *See id.* at 593 ("Many factors will bear on the inquiry, and we do not presume to set out a definitive checklist or test.").

60. *Id.*

61. *Id.*

62. Kumho Tire Co. v. Carmichael, 526 U.S. 137, 149 (1999) (quoting *Daubert*, 509 U.S. at 592–94).

63. *See id.* (explaining the *Daubert* factors).

> by the expert is known to reach reliable results for the type of opinion the expert would give.[64]

Forensic biomechanical analyses may not always fit nicely within the *Daubert* framework because "the case-specific nature of the inquiry makes it rarely publication worthy, subject to error rate calculations, or even testable in practice."[65] However, courts should still consider whether a biomechanical engineer's methodology is testable, whether its use raises error rate concerns (such as construct validity, external validity, internal validity),[66] and whether "there is simply too great an analytical gap between the data and the opinion proffered."[67] Where expert testimony depends on a chain of inferences or interlinked methodologies, "[a]ny step that renders the analysis unreliable . . . renders the expert's testimony inadmissible. This is true whether the step completely changes a reliable methodology or merely misapplies that methodology."[68]

3. Relevance

Federal Rule of Evidence 702 requires that expert testimony "help the trier of fact to understand the evidence or to determine a fact in issue."[69] Expert testimony must be "sufficiently tied to the facts of the case that it will aid the jury in resolving a factual dispute."[70] In a personal injury case, the causation dispute is "the

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64. *Id.* (quoting FED. R. EVID. 702, advisory committee's note (2000 amends.)).

65. *Cf.* 5 DAVID L. FAIGMAN ET AL., MODERN SCIENTIFIC EVIDENCE: THE LAW AND SCIENCE OF EXPERT TESTIMONY § 44:9 (2013–2014) (discussing the application of *Daubert* to accident reconstruction techniques); *see also* John B. Meixner & Shari Seidman Diamond, *The Hidden* Daubert *Factor: How Judges Use Error Rates in Assessing Scientific Evidence*, 2014 WIS. L. REV. 1063, 1080 (2014) ("[A]pplicable error rates are not available in many disciplines.").

66. *See id.* at 1067 (stating that where numerical error rates are unavailable, "the judge must examine the methodology for flaws that are likely to produce errors").

67. Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997).

68. Goebel v. Denver & Rio Grande W.R.R., 346 F.3d 987, 992 (10th Cir. 2003) (quoting Mitchell v. Gencorp Inc. 165 F.3d 778, 782 (10th Cir. 1999)).

69. FED. R. EVID. 702.

70. United States v. Downing, 753 F.2d 1224, 1242 (3d Cir. 1985); *see Daubert*, 509 U.S. at 591 ("'Fit' is not always obvious, and scientific validity for

degree to which [a] particular plaintiff[] [was] injured in this particular automobile accident."[71] Finally, otherwise relevant opinions may still be excluded if they are "substantially outweighed" by unfair prejudice or a risk of misleading the jury or confusing the issues.[72]

IV. Biomechanical Expert Qualifications

This Part applies the first prong of the *Daubert* standard to typical biomechanical expert qualifications. First, it discusses education, training, and experience common among biomechanical engineers. Next, it notes similarities between the field of biomechanics and the field of toxicology and discusses an emerging distinction between general and specific causation in personal injury litigation. It then discusses two notable cases, *Smelser*[73] and *Eskin v. Carden*,[74] to illustrate different approaches courts have taken to assess the scope of biomechanical expert qualifications. Finally, it argues that the *Smelser* approach—requiring medical expertise for specific injury causation opinions—is the most appropriate rule.

A. Typical Education, Experience, Skill, and Training

Witnesses claiming biomechanical expertise have diverse backgrounds. Many have an advanced degree in physiology, mathematics, physics, or mechanical engineering.[75] Less common

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one purpose is not necessarily scientific validity for other, unrelated purposes."); *see also* Daubert v. Merrell Dow Pharms., 509 U.S. 579, 591 (1993) ("Expert testimony which does not relate to any issue in the case is not relevant and, ergo, non-helpful." (quoting 3 J. WEINSTEIN & M. BERGER, WEINSTEIN'S EVIDENCE, § 702[02] (1991))).

71. Stedman v. Cooper, 292 P.3d 764, 768 (Wash. App. 2012).

72. FED. R. EVID. 403.

73. 105 F.3d 299 (6th Cir. 1997).

74. 842 A.2d 1222 (Del. 2004).

75. *See, e.g.*, *id.* at 1375 (noting degrees in physiology, mathematics, and chemistry); Morgan v. Girgis, No. 07 CIV. 1960, 2008 WL 2115250, at *4–5 (S.D.N.Y. May 16, 2008) ("Dr. Fijan is a mechanical engineer specializing in biomechanics. He holds a Ph.D. and an M.S. in mechanical engineering from the Massachusetts Institute of Technology and a B.S.E. in engineering science from

are degrees in areas such as physical education.[76] Some who claim to be qualified as biomechanical engineers took anatomy or physiology classes with first-year medical students.[77]

Some who claim biomechanical expertise teach courses such as engineering, physiology, anatomy, or exercise science.[78] Others are employed as consultants with experience in workplace ergonomics, occupational injury prevention, or vehicle and aircraft crashworthiness.[79] Some have conducted crash tests, vehicle sled tests, occupant kinematics analyses, or are involved in research on injury mechanics and human injury tolerance.[80]

While some schools, including Stanford University, offer a biomechanical engineering program, most schools do not.[81]

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the University of Florida."); Wilcox v. CSX Transp., Inc., No. 1:05-CV-107, 2007 WL 1576708, at *27 (N.D. Ind. May 30, 2007) ("These accomplishments are many as far as the study of physiology, health, and 'exercise science' are concerned.").

76. *See Wilcox*, 2007 WL 1576708, at *22 (discussing the qualifications of David Nieman, Ph.D.).

77. *See, e.g.*, Ruffin v. Boler, 890 N.E.2d 1174, 1182 (2008) (discussing the education of Michele Grimm, Ph.D.). In addition to attending courses at medical schools, some biomechanical engineers teach classes at medical schools in areas typically limited to anatomy or physiology. *See* Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1375 (M.D. Ga. 2007) (noting that John Trimble, Ph.D., a biomechanical engineer, taught courses in neuroanatomy and neurophysiology at a medical school).

78. *See supra* note 75 and accompanying text (discussing the education and experience of biomechanical engineers).

79. *See, e.g.*, Morgan v. Girgis, No. 07 CIV. 1960, 2008 WL 2115250, at *5 (S.D.N.Y. May 16, 2008) (noting the practical experience of Robert S. Fijan, Ph.D.); Laugelle v. Bell Helicopter Textron, Inc., No. 10C–12–054, 2014 WL 5038142, at *34 (Del. Super. Ct. Oct. 6, 2014) (noting that William Muzzy, a biomechanical engineer had "24 years of crash injury testing experience with human volunteers and 22 years of experience analyzing the effectiveness of occupant restraints in automotive and aircraft crashes," in addition to publishing articles on human tolerance to crash forces (internal quotation marks omitted)).

80. *See* cases cited *supra* note 62 (discussing the practical experience of witnesses found to have expertise in the field of biomechanics).

81. *See Biomechanical Engineering Major Program*, STAN. U., http://web.stanford.edu/group/ughb/cgi-bin/handbook/index.php/Biomechanical_Engineering_Major_Program (last visited Feb. 2, 2015) (detailing the requirements for an undergraduate degree in biomechanical engineering) (on file with the Washington and Lee Law Review); *see also Laugelle*, 2014 WL 5038142, at *10 n.85 (noting a biomechanical engineer's testimony that a biomechanical engineering degree "did not exist when he began his research in 1967").

Apparently, there is no single route to obtaining biomechanical expertise. However, an understanding of physics, mathematics, and engineering are helpful in order to make the calculations necessary for accident reconstruction.[82] Qualifications in biomedical engineering are typically necessary to perform computer simulations.[83] Qualifications in statistics are desirable in order to understand and apply biomechanical literature.[84] In addition, a medical degree is required to diagnose injury.[85] For these reasons, "[q]ualified experts in the field of . . . biomechanics are a rare breed. This discipline requires expertise in both mechanical engineering and in medical sciences."[86]

B. Smelser*: An Emerging Distinction Between General and Specific Causation*

Many courts that have considered the scope of biomechanical engineers' qualifications have cited favorably to the Sixth Circuit's reasoning in *Smelser*.[87] In *Smelser*, the United States

82. *See* Boykin v. W. Exp., Inc., No. 12-CV-7428, 2015 WL 539423, at *1 (S.D.N.Y. Feb. 6, 2015) (finding an expert not qualified in engineering but admitting accident reconstruction testimony due to extensive experience reconstructing the type of accident in question).

83. *See* K.S. Krishnan et al., *An Injury Threshold Model For Two-Car Collisions*, 29 MGMT. SCI. 909, 910 (1983) ("The study of occupant motion . . . is generally in the realm of biomedical science.").

84. *See* 1 DAVID L. FAIGMAN ET AL., MODERN SCIENTIFIC EVIDENCE: THE LAW AND SCIENCE OF EXPERT TESTIMONY § 6:3 (2007) ("Individuals who specialize in using statistical methods—and whose professional careers demonstrate this orientation—are more likely to apply appropriate procedures and correctly interpret the results.").

85. *See* Combs v. Norfolk & W. Ry. Co., 507 S.E.2d 355, 358 (Va. 1998) ("[T]he question of causation of a human injury is a component part of a diagnosis, which in turn is part of the practice of medicine.").

86. Eskin v. Carden, 842 A.2d 1222, 1229 n.12 (Del. 2004) (citation and internal quotation marks omitted).

87. *See* Kelham v. CSX Transp., Inc., No. 2:12-CV-316, 2015 WL 4426027, at *6 (N.D. Ind. July 17, 2015) ("Although not binding, this court will follow *Smelser* and the Sixth Circuit's reasoning."); Berner v. Carnival Corp., 632 F. Supp. 2d 1208, 1212 (S.D. Fla. 2009) (adopting the reasoning in *Smelser* and noting that "[o]ther courts that have considered whether a biomechanical engineer is qualified to testify about the cause of an injury have ruled consistently with *Smelser*"); Morgan v. Girgis, No. 07 CIV. 1960, 2008 WL 2115250, at *14 (S.D.N.Y. May 16, 2008) (adopting the reasoning in *Smelser*);

Court of Appeals for the Sixth Circuit held that it was an abuse of discretion to allow a biomechanic's testimony regarding an injury's precise cause because the engineer was not qualified to consider two things that could affect injuries resulting from an accident: First, "the different tolerance levels . . . of individuals," and second, the "pre-existing medical conditions of individuals."[88] The court found the engineer's expertise in biomechanics qualified him only to "describe[] the forces generated in the . . . collision, and [speak] in general about the types of injuries those forces would generate."[89]

Smelser implies that legal causation can be separated into two distinct sub-elements: general and specific injury causation.[90] This distinction is a settled principle in toxic tort litigation, but before *Smelser* was not used in traditional personal injury litigation.[91] General causation is concerned with whether a substance can cause harm.[92] In toxic tort cases, general causation refers to "epidemiological evidence indicating a consistent statistically significant relationship between exposure and

Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1377 (M.D. Ga. 2007) (same); Shires v. King, No. 2:05-CV-84, 2006 WL 5171770, at *8 (E.D. Tenn. Aug. 10, 2006) (same).

88. Smelser v. Norfolk S. Ry., 105 F.3d 299, 305 (6th Cir. 1997).

89. *Id.*

90. *Id.*

91. *See* 1 KAREN GOTTLIEB, TOXIC TORTS PRACTICE GUIDE § 15:3 (2014) (explaining that proof of causation in toxic tort litigation requires proof of both general and specific causation). *See also generally* Kerriann Laubach, Note, *Epigenetics and Toxic Torts: How Epidemiological Evidence Informs Causation*, 73 WASH. & LEE L. REV. 1019 (2016) (discussing the element of causation in toxic tort cases).

92. *See* 3 DAVID L. FAIGMAN ET AL., MODERN SCIENTIFIC EVIDENCE: THE LAW AND SCIENCE OF EXPERT TESTIMONY § 23:1 (2007) (explaining the difference between specific and general causation). The concept of general causation has its roots in work by Sir Austin Bradford Hill, an acclaimed English scientist of the 1900s who was a "pioneer in medical statistics and epidemiology." Michael Höfler, *The Bradford Hill Considerations on Causality: A Counterfactual Perspective*, 2 EMERGING THEMES EPIDEMIOLOGY 11, 11 (2005). Hill became famous for developing a list of considerations for determining "whether an observed association involved a causal component or not," including consistency, specificity, temporality, biological plausibility, experiment, analogy, and others. *Id.*; *see also* Austin Bradford Hill, *The Environment and Disease: Association or Causation?*, 58 PROC. ROYAL SOC. MED. 295, 295–300 (1965) (listing eight relevant factors when considering whether an observed association is a causal relationship).

injury."[93] The analog in personal injury litigation would be population-based evidence showing a relationship between a type of traumatic force and a type of injury.[94]

Specific causation, on the other hand, is concerned with whether a substance caused the plaintiff's injury.[95] The equivalent in personal injury cases is whether a traumatic incident caused the plaintiff's injury.[96] Translating this distinction into personal injury terms, biomechanical experts enter the realm of specific causation when they opine that a trauma did or did not cause the plaintiff's injuries.[97]

C. Toxicology and Biomechanics: An Analogy

The adoption of a toxic tort causation principle may seem odd, but comparing the fields of toxicology and biomechanics reveals striking similarities. Toxicologists and biomechanical engineers both seek to answer the same basic questions: (1) "What hazards does [an exposure] present to human populations . . . ?" and (2) "What degree of risk is associated with . . . [an] exposure at any given dose?"[98]

Researchers in the two fields share many dilemmas. For example, "it is often unethical to experiment on humans," and humans are only rarely exposed "in a manner that permits a quantitative determination" of cause and effect.[99] In addition, the data available in either field is limited in the number of "case reports, or even experimental studies [performed] . . . under

93. *See* DAVID L. FAIGMAN ET AL., *supra* note 92, § 23:3.

94. *See* Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1355 (M.D. Ga. 2007) (discussing whether vibration is causally linked to injury).

95. *See* 3 DAVID L. FAIGMAN, *supra* note 92, § 23:1 (explaining the difference between specific and general causation).

96. *See* Burke v. TranSam Trucking, Inc., 617 F. Supp. 2d 327, 334 (M.D. Pa. 2009) (noting that specific causation opinions include the extent of the injuries suffered by the plaintiff).

97. *See infra* notes 134–139 (collecting cases that help define the boundary between general and specific causation opinions).

98. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 637 (listing difficulties in the science of toxicology). In toxicology, exposures are substances, while in biomechanics exposures are types of forces. The term "dose" in toxicology translates to a degree of force in biomechanics.

99. *Id.* at 636.

circumstances that permit analysis of dose-response relationships, [or] mechanisms of action."[100] Research in both fields is also hindered by the fact that "human sensitivity . . . can vary greatly among individuals."[101]

The application of information from either field requires "extrapolation, either across species . . . or across doses." Finally, both fields rely on medical examinations and diagnoses to confirm that subjects are ill or injured.[102] These similarities may explain why *Smelser* adopted the distinction between general and specific causation.[103]

D. The Smelser *Rule: Medical Expertise Is Necessary to Offer Specific Causation Opinions*

Toxicologists who give specific causation testimony in court must show that they are not only qualified to testify about population-based research but also to take and interpret a medical history, perform a physical examination, administer medical tests, and to understand the "time pattern of symptoms and disease manifestations" and the constellation of symptoms that support or rule out causation.[104] The *Smelser* line of cases

100. *Id.* at 639.

101. *Id.* at 642; *see also* Laubach, *supra* note 91, at 1040–41 (discussing the use of dose-response curves in proving causation in toxic tort cases, and stating, "[a]lthough these curves are useful for quantifying disease risk, they can vary for each individual, depending on genetic, epigenetic, and environmental factors—and a combination of all three."); FEDERAL JUDICIAL CENTER, REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 639 (3d ed. 2011) (describing toxicological study designs); Hayes et al., *supra* note 33, at 58 (proposing a method to revise population-based biomechanical criteria to apply to individuals).

102. *See id.* at 670–71 (stating that specific causation opinions regarding toxic exposures require an "examination of the patient as well as appropriate medical testing," in addition to a review of medical records).

103. *See, e.g.*, Earl v. Cryovac, 772 P.2d 725, 726 (Idaho Ct. App. 1989) (applying the general-specific causation requirements in a toxic tort case).

104. *Compare* FEDERAL JUDICIAL CENTER, *supra* note 101, at 667–74 (noting that relevant individual characteristics in the context of toxic substances include physical activity, age, sex, genetic makeup, dose, route of entry, tissue solubility, metabolism, personal and family medical history, symptomology, and interaction with other chemicals), *with* L. Uhrenholt et al., *Degenerative and Traumatic Changes in the Lower Cervical Spine Facet Joints*, 37 SCAND. J. RHEUMATOLOGY 375, 380–83 (2008) (discussing the effects of age, sex, and prior

indicate that biomechanical experts must have similar medical expertise before giving specific injury causation opinions.[105]

One difference between toxicology and biomechanics is that "many highly qualified toxicologists are physicians"[106] and therefore are qualified to fill both scientific and medical roles, while biomechanical engineers with medical degrees are rare.[107] As a general rule, biomechanical engineers lack the education required to examine a plaintiff, take medical tests, thoroughly review and understand medical records, including diagnostic imaging, identify relevant symptoms, or rule out alternative causes of those symptoms.[108] Therefore, courts adopting the *Smelser* distinction between specific and general causation have

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traumatic history on the lower cervical spine's characteristics and susceptibility to traumatic injury), *and* Jacqueline R. Center et al., *Risk of Subsequent Fracture After Low-Trauma Fracture in Men and Women*, 297 J. AM. MED. ASS'N 387, 393 (2007) (examining absolute as well as relative re-fracture risks in a cohort study), *and* David J. Daegling et al., *Structural Analysis of Human Rib Fracture and Implications for Forensic Interpretation*, 53 J. FORENSIC SCI. 1301, 1305–06 (2008) (noting the potential for large individual differences in bone porosity and mineralization, leading to individual differences in bone brittleness), *and* Caroline F. Finch et al., *supra* note 27, at 65 (stating that tissue strength plays a role in injury causation and varies by age and sex, and can increase or decrease based on training and lifestyle).

105. *See* Smelser v. Norfolk S. Ry., 105 F.3d 299, 305 (6th Cir. 1997) (criticizing a biomechanical engineer's failure to examine complete medical records and discuss symptomology with the plaintiff); Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1378 (M.D. Ga. 2007) (finding no evidence that a biomechanical engineer was capable of interpreting x-rays and was not familiar with potentially relevant medical conditions); Eskin v. Carden, 842 A.2d 1222, 1231 (Del. 2004) (finding a biomechanical engineer incompetent to properly review medical records or examine the plaintiff, and stating that no evidence suggested "that any expert in his field would be competent, or would have taken the opportunity to do so"); Harden v. Haven, No. 05-2009-CA-065372, 2014 Fla. Cir. LEXIS 815, at *13 (Fla. Cir. Ct. Feb. 10, 2014) (noting that a biomechanical expert was also "a qualified medical doctor, who can discuss specific causation and medical issues, in addition to general causation issues at a biomechanic level").

106. FEDERAL JUDICIAL CENTER, *supra* note 101, at 675.

107. *See supra* notes 75–76 and accompanying text (listing common undergraduate and graduate degrees obtained by biomechanical engineers).

108. *See* cases cited *supra* note 105 (pointing out areas where biomechanical engineers are unqualified); *Harden*, 2014 Fla. Cir. LEXIS 815, at *13 (discussing the qualifications of a biomechanical engineer who was also a qualified medical doctor).

typically limited biomechanical engineers' testimony to opinions that concern injury causation in general.[109]

E. Clarifying the Distinction Between General and Specific Causation

Drawing a line between general and specific causation is not always easy.[110] Some courts attempting to apply *Smelser* reach apparently inconsistent outcomes.[111] Some variation in interpretation is hardly surprising because the distinction between specific and general causation in the personal injury context is relatively new.[112]

While the dividing line is not crystal clear, general causation opinions should probably include testimony about which of multiple competing mechanisms was more likely to cause an injury[113] and whether population-based studies show a

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109. *See* Berner v. Carnival Corp., 632 F. Supp. 2d 1208, 1213 (S.D. Fla. 2009) (excluding biomechanical experts' specific causation opinions); Wagoner v. Schlumberger Tech. Corp., No. 07-CV-244-J, 2008 WL 5120750, at *2 (D. Wyo. June 19, 2008) (excluding biomechanical experts' specific causation opinions); Morgan v. Girgis, No. 07 CIV. 1960, 2008 WL 2115250, at *10 (S.D.N.Y. May 16, 2008) (limiting biomechanical expert testimony to general causation opinions); Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1376 (M.D. Ga. 2007) (same).

110. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 460 (noting that specific and general causation "are inextricably interwoven, inasmuch as specific causation depends on principles of general causation, and general causation is based upon a foundation of individual cases of specific causation").

111. *Compare* Wagoner v. Schlumberger Tech. Corp., No. 07-CV-244-J, 2008 WL 5120750, at *1 (D. Wyo. June 19, 2008) (excluding biomechanical expert testimony that "the impact force was sufficient to cause a traumatic brain injury"), *and* Stedman v. Cooper, 292 P.3d 764, 769 (Wash. App. 2012) (excluding testimony that "the forces generated by the impact were not sufficient to cause the type of injuries [the plaintiff] was claiming"), *with* Berner v. Carnival Corp., 632 F. Supp. 2d 1208, 1213 (S.D. Fla. 2009) (allowing biomechanical expert testimony that the "energy on [plaintiff's] head upon striking the floor was sufficient to have caused his mild to moderate traumatic brain injury" (internal quotation marks omitted)).

112. *See* Smelser v. Norfolk S. Ry., 105 F.3d 299, 306 (6th Cir. 1997) (remanding for entry of a judgment as a matter of law due to the plaintiff's inability to prove causation by biomechanical expert testimony alone).

113. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 458 (noting that the discipline of forensic biomechanics is best suited to "analyzing how injuries occur and in differentiating between competing injury

heightened risk for injury at a given level of force.[114] Specific causation opinions, on the other hand, often take the form of a conclusion that an injury was or was not caused by an event.[115]

Examples of biomechanical expert opinions that courts have labeled "specific" include the following:

- "It is impossible . . . to conclude that the degenerative disease in [plaintiff's] cervical and lumbar spines can be attributed to the incident."[116]
- "The accident did not contribute in any significant way to disc bulges . . . or other associated pathologies of [plaintiff's] . . . spine."[117]
- "[T]he 'motion' at issue in this case caused 'brain damage' to plaintiff."[118]
- "[T]he defective shoulder belt, not the rear-end collision, caused [plaintiff's] back injuries and aggravated . . . neck injuries."[119]
- "The forces on her body in this accident did not result in a concussion injury."[120]

In comparison, biomechanical expert opinions that courts have found to be "general" include the following:

- The "energy on [plaintiff's] head upon striking the floor was sufficient to have caused his mild to moderate traumatic brain injury."[121]

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mechanisms for observed injuries").

114. FEDERAL JUDICIAL CENTER, *supra* note 101, at 24 (stating that population-based studies that show some increased risk may "have some probative value . . . in proving general causation").

115. *See, e.g.*, Wilcox v. CSX Transp., Inc., No. 1:05-CV-107, 2007 WL 1576708, at *12 (N.D. Ind. May 30, 2007) (excluding opinions relating to the cause of the plaintiff's particular condition as specific causation opinions beyond the expertise of the biomechanical engineer).

116. Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1376 (M.D. Ga. 2007) (internal quotation marks omitted).

117. Morgan v. Girgis, No. 07 CIV. 1960, 2008 WL 2115250, at *10 (S.D.N.Y. May 16, 2008) (quotation marks omitted).

118. Wagoner v. Schlumberger Tech. Corp., No. 07-CV-244-J, 2008 WL 5120750, at *2 (D. Wyo. June 19, 2008).

119. Smelser v. Norfolk S. Ry., 105 F.3d 299, 302 (6th Cir. 1997).

120. Roach v. Hughes, No. 4:13-CV-00136-JHM, 2015 WL 3970739, at *12 (W.D. Ky. June 30, 2015).

121. Berner v. Carnival Corp., 632 F. Supp. 2d 1208, 1213 (S.D. Fla. 2009) (internal quotation marks omitted).

- "[T]he forces [plaintiff] generated in her . . . spine[] during the subject accident were well below thresholds for damage . . . as reported in the biomechanics literature."[122]

The difference between specific and general causation opinions might seem semantic, but the distinction has significant legal consequences. For example, if a court applies the *Smelser* rule, a litigant relying solely on a biomechanical engineer to prove or rebut causation probably will not survive summary judgment or a motion for a directed verdict.[123]

The adoption of the *Smelser* distinction has raised a question about whether both general and specific causation must be proven to make out a prima facie personal injury claim. Some biomechanical engineers argue that general causation evidence is always necessary and that medical doctors who lack expertise in biomechanics are unqualified to establish general causation.[124]

This may be true in some cases. For example, in *Bowers v. Norfolk Southern Corp.*,[125] two of the plaintiff's medical experts claimed that locomotive vibration caused injury to the plaintiff's spine.[126] In rebuttal, the defendant's biomechanical engineer collected biomechanical literature, estimated the amount of vibration experienced by the plaintiff,[127] and opined that the force was not sufficient to cause the plaintiff's injuries.[128]

Applying *Daubert*, the district court in *Bowers* found the medical doctors' premise that vibration could cause injury "too vague to have any meaning for a *Daubert* analysis," especially because the plaintiff's medical experts admitted that "not all vibration can cause harm."[129] The district court excluded the

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122. *Morgan*, 2008 WL 2115250, at *9–10.

123. *See id.* (stating that the biomechanical engineer was the "only witness whose testimony connects [plaintiff's] injuries to the allegedly defective shoulder belt" and finding that, absent the improper testimony, the defendant's motion for a directive verdict should have been granted).

124. *See supra* note 17 and accompanying text (discussing biomechanical engineers' critiques of medical doctors' causation opinions).

125. 537 F. Supp. 2d 1343 (M.D. Ga. 2007).

126. *See id.* at 1353 (summarizing an orthopedist's expert opinions).

127. *See id.* at 1375–76 (referencing the expert report of John Trimble, Ph.D.).

128. *See id.* (describing Dr. Trimble's causation opinions).

129. *Id.* at 1355.

medical doctors' opinions altogether, finding that the doctors failed to establish general causation.[130] Notably, the district court also excluded the biomechanical engineer's specific causation opinions due to his lack of medical qualifications.[131]

The exclusion of the medical experts' causation opinions in *Bowers* is rare for two reasons. Commentators have observed that plaintiffs can often establish a prima facie personal injury case without general causation evidence,[132] especially when "the mechanism of causation is well understood, the causal relationship is well established, or the timing between cause and effect is close."[133] In addition, courts have found medical doctors qualified to opine regarding all aspects of injury causation as long as there is no conclusive evidence that contradicts the medical doctors' general causation opinions.[134] Therefore, plaintiffs must establish general injury causation only in rare cases where the mechanism of injury is not commonly associated with injury.[135]

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130. *See id.* at 1355 (noting a lack of evidence regarding the "amount of vibration that is harmful to an individual, the length of time over which such harm normally occurs" and "the nature of the resulting harm").

131. *Id.*

132. RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYS. AND EMOT. HARM § 28, cmt. c(3) (2010) ("[M]ost courts have appropriately declined to impose a threshold requirement that a plaintiff always must prove causation with epidemiologic evidence.").

133. FEDERAL JUDICIAL CENTER, *supra* note 101, at 609 n.180.

134. *See* Wells v. Ortho Pharm. Corp., 788 F.2d 741, 745 (11th Cir. 1986) ("[A] cause-effect relationship need not be clearly established before a doctor can testify that, in his opinion, such a relationship exists. As long as the basic methodology . . . is sound . . . products liability law does not preclude recovery until a 'statistically significant' number of people have been injured . . . ."); Burton v. R.J. Reynolds Tobacco Co. 181 F. Supp. 2d 1256, 1266–67 (D. Kan. 2002) (allowing a vascular surgeon to testify to general causation over objections that the expert was not an epidemiologist); *see also* Layssard v. United States, No. 06-0352, 2007 WL 4144936, at *7–8 (W.D. La. Nov. 20, 2007) (allowing a medical doctor to testify regarding causation and stating, "Put simply, medical doctors are qualified—indeed, uniquely qualified—to offer opinions as to medical causation; bio-mechanical engineers are not").

135. *See* Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1355 (M.D. Ga. 2007) (stating that the unusually complex issue of causation stemming from unknown amounts of vibration required evidence of the link between levels of vibration and injury).

F. Eskin v. Carden*: An Alternative to the* Smelser *Rule*

Not all courts adopt the *Smelser* distinction.[136] The Supreme Court of Delaware, for example, has made no attempt to distinguish between general and specific causation in personal injury litigation. In *Eskin v. Carden*,[137] the Supreme Court of Delaware held that trial judges may admit biomechanical experts' opinions that a particular injury did (or did not) result from the forces of an accident "only where the trial judge determines that the testimony reliably creates a connection between the reaction of the human body generally to the forces generated by the accident and the specific individual allegedly injured."[138]

Simply put, the *Eskin* approach implies that biomechanical experts are qualified to offer any type of causation opinion as long as the methods used are reliable. *Eskin* also suggests that typical biomechanical methodologies will be acceptable when a plaintiff's characteristics "fairly represent the average human body."[139] Time has shown that courts adopting the *Smelser* rule exclude specific causation opinions under the qualifications prong of the *Daubert* analysis, while courts following the *Eskin* approach exclude some of the same opinions under the reliability prong due to a lack of testability, error rate, or "fit."[140] The application of the reliability prong is discussed in more detail in Part V.

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136. *See, e.g.*, Eskin v. Carden, 842 A.2d 1222, 1230 (Del. 2004) (making no reference to *Smelser* and drawing no distinction between general and specific causation).

137. 842 A.2d 1222 (Del. 2004).

138. *Id.* at 1230.

139. *Id.* What may be the most common forensic biomechanical methodology is discussed in Part V.

140. *See id.* at 1232 (excluding biomechanical expert testimony that failed to establish a link between generic injury thresholds and a unique individual); Mason v. Rizzi, 89 A.3d 32, 38 (Del. 2004) (excluding generalized biomechanical expert testimony due to unhelpfulness, risk of misleading the jury, and unfair prejudice).

G. The Smelser *Rule is The Best Approach to Biomechanical Expert Qualifications*

The *Eskin* approach overestimates the ability of engineers to adapt statistical curves in the biomechanical literature to any individual plaintiff.[141] Another flaw in the *Eskin* approach is that the scope of allowable testimony hinges on a difficult question: whether the plaintiff's body represents the "average human body." Delaware courts have struggled to decide whether plaintiffs fall within the "norm" described in *Eskin*.[142] In reality, even individuals who are young, healthy, and apparently "normal" can be injured by forces below 1% on statistical risk curves,[143] and biomechanical science offers no way to identify which individuals will fall predictably along the statistical curve and which will not.[144]

The Sixth Circuit's approach in *Smelser* is the better rule because biomechanical engineers are typically unqualified to examine individuals or adapt generalized data to specific circumstances.[145] The appropriateness of the adoption of the

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141. *See supra* note 104 and accompanying text (discussing the inability of biomechanical engineers to adapt general statistics to consider lifestyle, age, sex, or pre-existing medical conditions which may play a role in injury causation).

142. *See* Smith v. Grief, No. 308-2014, 2015 WL 128004, at *2 (Del. Jan. 8, 2015) (refusing to upset a trial court's decision to allow biomechanical testimony regarding the precise cause of an individual's injuries despite the fact that the plaintiff was pregnant); *Mason*, 89 A.3d at 38 (excluding a biomechanical engineer's causation opinions as lacking a connection to the plaintiff's characteristics where the plaintiff had pre-existing spinal injuries); DiVirgilio v. Eskin, No. 02C-02-169, 2005 WL 2249530, at *2 (Del. Super. Ct. June 29, 2005) (excluding a biomechanical engineer's opinions regarding precise causation of injuries because the plaintiff was in an "unusual physical position" at the moment of impact); Frazier v. Leotta, 54 A.3d 1134, 1148 (Del. Super. Ct. 2010) (stating that the court was unsure whether a plaintiff who had apparently recovered from pre-existing conditions fell within the "norm" mentioned in *Eskin* and requesting further testimony on the issue).

143. *See* J.R. Funk et al., *Biomechanical Risk Estimates for Mild Traumatic Brain Injury*, 51 ANN. PROC. ASS'N ADVANCEMENT AUTOMOTIVE MED. 343, 357–58 (2007) (reporting that a college football player suffered a concussion caused by only eighty-one g-force of acceleration).

144. *See id.* (attributing wide variances in forces causing injury to football players to "variation in injury tolerance between individuals").

145. *See supra* note 104 and accompanying text (discussing the inability of biomechanical engineers to adapt general statistics to consider lifestyle, age,

distinction between general and specific causation is supported by the compelling similarities between biomechanics and toxicology.[146] In addition, as discussed in Part V, even if biomechanical engineers were qualified to offer specific injury causation testimony, biomechanical methodologies are incapable of determining specific injury causation with the degree of reliability required under *Daubert*.[147]

The adoption of the *Smelser* rule does not affect biomechanical engineers' general causation opinions.[148] Competent biomechanical engineers usually have the education and experience necessary to calculate forces and testify about how collisions can be expected to affect the human body based on statistics in the biomechanical literature.[149] Biomechanical engineers' general causation opinions, however, must still assist the trier of fact, be relevant and reliable, provide an adequate "fit" to the facts of the case, be based on admissible data, and must not be unfairly prejudicial.[150]

V. The Reliability of Forensic Biomechanical Methodologies

This Part applies *Daubert* to typical biomechanical methodologies and argues that those considerations weigh against the admission of opinions based on extrapolation from generic injury thresholds. Finally, this Part argues that

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gender, sex, or pre-existing medical conditions that may play a role in injury causation).

146. *See supra* Part IV.C (drawing an analogy between toxicology and biomechanics).

147. *See infra* Part V.C (analyzing the accuracy of biomechanical methods when used to predict injury causation).

148. *See, e.g.*, Berner v. Carnival Corp., 632 F. Supp. 2d 1208, 1211 (S.D. Fla. 2009) (allowing biomechanical engineer testimony that accepted "the injuries as diagnosed by other doctors" and focused "on the forces involved in the blows sustained by [Berner] and . . . the levels at which certain injuries may occur").

149. *See, e.g.*, Bowers v. Norfolk S. Corp., 537 F. Supp. 2d 1343, 1378 (M.D. Ga. 2007) (applying the reasoning in *Smelser* to conclude that a biomechanical engineer could "testify generally as to the effect of locomotive vibration on the human body and the typical injuries that may result").

150. Judge Harvey Brown, *Eight Gates for Expert Witnesses*, 36 HOUS. L. REV. 743, 746–50 (1999) (listing prerequisites for admissible expert testimony).

biomechanics' forensic analyses are not a reliable basis for opinions ruling out general injury causation but may be a reliable basis for opinions supporting general causation.

A. A Basic Overview of Forensic Biomechanics

Engineers calculate the "factor of safety" of a bridge, structure, or other physical material by measuring its failure strength against "the expected stress that object will see in service."[151] This analysis parallels the basic approach of some leading biomechanical experts in personal injury litigation.[152] Biomechanics sometimes use a slightly modified ratio, known as the "factor of risk," to estimate risk of injury.[153] The basic equation divides an anatomical region's tolerance by the force applied to that region.[154] If the equation produces a number greater than one, the relative risk of injury is more probable than not.[155]

The factor of risk equation requires at least two variables: (1) the level of force an anatomical region can tolerate without injury, and (2) the amount of force applied to the anatomical structure.[156] To discover these variables, biomechanical engineers have developed a three-step analysis:[157] (1) accident reconstruction; (2) simulation of kinematics; and (3) comparing estimated forces to injury risk curves documented in the biomechanical literature.[158] These three methodologies should be considered separately.

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151. *See* Joseph C. Musto, *The Safety Factor: Case Studies in Engineering Judgment*, 38 INT'L J. MECHANICAL ENGINEERING EDUC. 286, 286–88 (2010) (discussing the use of the safety factor in engineering education).

152. *See* Hayes et al., *supra* note 33, at 60 (comparing the factor of risk and factor of safety equations).

153. *Id.* at 60.

154. *Id.*

155. *See id.* (stating that a result of "1" equals a 50% likelihood for injury and that any likelihood greater than 50% is "probable").

156. This does not capture the various methodologies used by every biomechanical engineer; it only illustrates a common approach.

157. *See* Wilson C. Hayes et al., *supra* note 33, at 68 (outlining a three-step approach for forensic biomechanical inquiries).

158. *See id.* (detailing the three-step analysis).

B. Accident Reconstruction

A biomechanical expert must discover the severity of forces in an accident before creating a computer simulation or comparing forces against injury thresholds.[159] Accident reconstruction involves "collecting information about a collision, appl[ying] standard engineering principles to this information, and determin[ing] the most probable sequence of events."[160] Many of the basic techniques of accident reconstruction are well settled.[161]

Other commentators have discussed various accident reconstruction methodologies in detail.[162] For the purposes of this Note, it is sufficient to mention that accident reconstruction testimony is often admitted unless, for example, it relies on photographs of vehicle damage, experience, or data that is plainly incorrect.[163] Results of the accident reconstruction are used as inputs for the next phases of the three-step analysis,[164] so inaccurate accident reconstruction methods will render the entire analysis unreliable.[165]

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159. *See id.* (outlining the three-step approach to biomechanical analyses, with the first two steps conducted for the purpose of calculating forces).

160. Clay v. Ford Motor Co., 215 F.3d 663, 668 (6th Cir. 2000).

161. *See* 9 AMERICAN JURISPRUDENCE, PROOF OF FACTS 115, § 12 (3d ed. 1990) (listing equations commonly used in accident reconstruction).

162. *See id.* (detailing aspects of accident reconstruction, including admissibility under *Daubert*, and collecting cases).

163. *See, e.g.*, Clemente v. Blumenberg, 705 N.Y.S.2d 792, 794 (N.Y. App. Div. 1999) (applying both the *Frye* and *Daubert* standards to find that "[u]sing repair costs and photographs as a method for calculating the change in velocity of two vehicles at impact is not a generally accepted method in any relevant field of engineering or under the laws of physics"); Reali v. Mazda Motor of Am., Inc., 106 F. Supp. 2d 75, 77 (D. Me. 2000) (finding accident reconstruction opinions unreliable where the expert "derived the 12 m.p.h. figure in large part from eyeballing accident photographs").

164. *See* Krishnan et al., *supra* note 83, at 910 (noting that crash severity, which is within the scope of accident reconstruction, includes "many factors such as the direction of impact force, impact speed, crush characteristics of the impact area, etc.," which are used as inputs when simulating occupant movements).

165. *See* Reali v. Mazda Motor of Am., Inc., 106 F. Supp. 2d 75, 77–78 (D. Me. 2000) (excluding biomechanical engineer expert testimony as irrelevant after concluding that the engineer's method of "eyeballing" photographs to estimate delta-V based on his experience was unreliable and stating that delta-V is "[a]n important data point" in creating a simulation).

C. Simulation of Kinematics

While accident reconstruction is within the realm of engineering, "[t]he study of occupant motion . . . is generally in the realm of biomedical science."[166] To simulate body movement and forces, experts rely on complex computer programs that apply the laws of physics in virtual environments.[167] These computer programs allow researchers to perform parametric studies to test vehicle design and safety features without the cost and time otherwise necessary to build parts and crash vehicles.[168] The distinct features, measurements, weights and stiffness values of each make and model of vehicle must be input into this virtual environment using defined contact surfaces.[169] In addition, minute details like seatbelt material or the seatbelt spooling response must be included in the simulation.[170]

The virtual occupants in these programs exist as ellipsoids connected by joints; for example, one ellipsoid represents a head while another represents a neck, and a mathematical formula defines the interaction between the two.[171] The properties of these ellipsoids are based on crash test dummies and are scaled to different sizes using measurements from anthropometry surveys.[172] It goes without saying that this method is imperfect. For example, it is impossible to model the movement of the seven vertebrae of a human neck with a single ellipsoid.[173] This modelling is even more unreasonable when the plaintiff, like Mrs.

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166. Krishnan et al., *supra* note 83, at 910.

167. *See* Hayes et al., *supra* note 33, at 69 (describing computer simulation programs).

168. Terry D. Day & Randall L. Hargens, *Application and Misapplication of Computer Programs for Accident Reconstruction*, SAE TECH. PAPER 890738, Feb. 1, 1989, at 129 (noting the uses of computer programs by government agencies, vehicle manufacturers, police, and insurance companies).

169. *See* Michael B. James et al., *Limitations of ATB/CVS as an Accident Reconstruction Tool*, SAE TECH. PAPER 971045, Feb. 24, 1997, at 1 (discussing the process of building a computer simulation).

170. *See id.* at 6 (discussing the difficulties of simulating seat belts).

171. *See id.* at 1 (discussing the process of building a computer simulation).

172. *See id.* at 6 (describing the process of compiling data for simulation ellipsoids).

173. *See id.* ("The joint parameters which are most critical in evaluating occupant injury exposure are also the most difficult to define; namely those characterizing the neck.").

Crandall in the Introduction, has fusions or other irregularities.[174]

1. Computer Program Validity and Peer Review

When considering the admissibility of opinions based on computer simulations, courts should first ensure that the program has been validated in peer-reviewed literature for the type of incident the expert is attempting to model.[175] Due to simplifications that must be made to create a computer model, even a generally accepted computer simulation program that is "based on the laws of physics and accepted principles of accident reconstruction[] is not a reliable methodology in all factual circumstances."[176] Without validation, courts cannot determine whether a computer model reliably simulates the accident at issue.[177]

2. Error Rate and the "Fit" of a Simulation to the Facts of a Case

Validation studies for some of the most prominent programs have reported rates of error as low as 2% to 17%.[178] While some courts have admitted opinions on the strength of these error rates alone,[179] judges should also consider whether the computer

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174. *See supra* Part I (setting forth the story of Mrs. Crandall).

175. *See* Turner v. Liberty Mut. Fire Ins. Co., No. 07 Civ. 163, 2007 WL 2713062, at *3–4 (N.D. Ohio Sept. 14, 2007) (finding a computer simulation program validated where it was subject to peer review and publication, has known error rates, and is generally accepted by the relevant scientific community).

176. Valente v. Textron, Inc., 931 F. Supp. 2d 409, 421 (E.D.N.Y. 2013) (internal quotation marks and citations omitted).

177. *See id.* (excluding opinions based on a computer simulation where the expert failed to show that the program had been tested or validated in any way for a scenario similar to the crash at issue).

178. *See* Hayes et al., *supra* note 33, at 69 (listing published error rates for the Engineering Dynamics Simulation Model of Automobile Collisions and the ATB).

179. *See, e.g.*, Melberg v. Plains Mktg., L.P., 332 F. Supp. 2d 1253, 1258, 1261 (D.N.D. 2004) (finding the use of the ATB computer simulation "somewhat suspect" but allowing opinions based on the simulation because the computer program was relied on by the Air Force and government agencies).

program is capable of fitting the facts of their specific case and whether the expert's opinion takes into account the limitations of the simulation.[180]

As an illustration of the limitations of computer simulations, authors of one validation study commented that "[t]he passenger's injuries were . . . difficult to compare because of the ejection and their severity. While severe injuries were evident in both the accident and simulation, the multiple impacts make it hard to determine the exact causes."[181] The authors concluded that "[a]lthough [the simulations] may not exactly reconstruct the accident events, they do provide likely occupant responses that can be used in parameter studies investigating injury countermeasures."[182]

In another example, researchers validating the "Articulated Total Body" model (ATB) produced a reasonably good modeling of occupant responses but noted the need for sufficient input data to obtain the desired results.[183] The authors concluded that "significant variations . . . result from moderate changes in the initial position of the occupant's body and his seat and angular configuration"[184] and that the simulation was "capable of delivering reasonable peak-level acceleration results and approximate time intervals, once appropriate vehicle and occupant mass, stiffness, energy dissipation, seat back and occupant position data are input."[185] Computer models require thousands of input parameters to produce results with levels of accuracy that compare with the rates of error published in validation studies.[186] Many more variables are available during

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180. *See* Day & Hargens, *supra* note 168, at 136 (warning that validated computer programs can be unreliable when misused).

181. *See* Huaining Cheng et al., *ATB Model Simulation of a Rollover Accident with Occupant Ejection*, SAE TECH. PAPER 950134, Feb. 1, 1995, at 30 (describing the collision and injuries).

182. *Id.*

183. I.U. Ojalvo & H. Yanowitz, *Vehicle and Occupant Response to Low Speed Impact: Comparison of Analysis with Test and Parametric Study*, SAE TECH. PAPER 980300, Feb. 23, 1998, at 4 (noting that only one of several controlled crash tests provided enough inputs to perform the study).

184. *Id.*

185. *Id.* at 1.

186. *See* James et al., *supra* note 169, at 1 (noting that the Articulated Total Body (ATB) program contains between 3,000 and 7,000 parameters).

controlled laboratory validations than exist in real-world investigations.[187]

Validation studies suggest two ways experts could misuse computer simulations. First, an expert might represent that a simulation shows the way an accident actually occurred or how an individual actually moved during a collision, rather than just one possible way the occupant might have moved.[188] Second, an expert might rely on a simulation that lacks sufficient input data.[189]

To avoid misuse, scholars have recommended that experts run a series of simulations to test for sensitivity to error attributable to missing variables and present data as a range of possible results.[190] Despite these suggestions, many courts have not excluded opinions based on computer simulations despite apparent deficiencies, reasoning that defects go to the weight and not admissibility of the expert's opinion.[191] Still, judges should be wary of opinions based on computer simulations where there is simply "too great an analytical gap between the data and the opinion."[192]

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187. *See id.* (noting that many of the input parameters may not be available for real-world collisions); L.A. Obergefell, I. Kaleps & A.K. Johnson, *Prediction of an Occupant's Motion During Rollover Crashes*, SAE TECH. PAPER 861876, Oct. 1986, at 14 (stating that "considerable information is required for the simulation of a crash test" and listing necessary parameters).

188. *See* Day & Hargens, *supra* note 168, at 136 (warning against the use of a single simulation to represent the only way a crash could have happened).

189. *See* Valente v. Textron, Inc., 931 F. Supp. 2d 409, 426 (E.D.N.Y. 2013) (excluding a computer simulation of a roll-over accident in part due to simplifications in the operation of the model).

190. *See* Day & Hargens, *supra* note 168, at 136 (listing recommendations to guard against the erroneous use of computer programs by forensic experts).

191. *See, e.g.*, Melberg v. Plains Mktg., L.P., 332 F. Supp. 2d 1253, 1258, 1261 (D.N.D. 2004) (finding the use of the ATB computer simulation "somewhat suspect" and stating that "[t]he expert opinions are weak but, . . . the appropriate means of attacking shaky but admissible evidence is through cross-examination"); Burke v. TranSam Trucking, Inc., 617 F. Supp. 2d 327, 335 (M.D. Pa. 2009) ("Defendants' arguments and criticisms of Dr. Ziejewski's methodology and inputs used went more to the weight of the evidence, rather than to his ability to testify as an expert in this case.").

192. *See* Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997) (recognizing that "[t]rained experts commonly extrapolate from existing data," but this does not warrant admitting opinion based "only by the ipse dixit of the expert").

D. Comparison to Documented Injury Thresholds

The two methods discussed above culminate in the approximation of forces applied to anatomical regions.[193] The final step in the three-step biomechanical analysis involves the comparison of those forces against documented injury thresholds.[194]

1. The Nature of Biomechanical Injury Thresholds

Biomechanical injury thresholds are based on experimental studies that aim to uncover causal links and risk curves in populations.[195] Researchers attempting to discover human injury thresholds encounter a paradox: the thresholds can be properly tested "only by using the human subject, but the tests cannot be performed in a manner to jeopardize his well-being or life."[196] Because controlled tests of humans are often ethically impossible, researchers have resorted to testing cadavers,[197] live volunteers in limited circumstances,[198] and animals.[199] Researchers then

193. *See* Hayes et al., *supra* note 33, at 68 (outlining a three-step approach to biomechanical analyses, with the first two steps conducted for the purpose of calculating forces).

194. *See id.* (outlining the three-step method).

195. *See id.* at 58–60 (discussing several statistical injury risk curves).

196. *See* Edwin Hendler et al., *Effect of Head and Body Position and Muscular Tensing on Response to Impact*, *in* HUMAN SUBJECT CRASH TESTING: INNOVATIONS AND ADVANCES 218 (Lawrence S. Nordhoff Jr., Michael D. Freeman & Gunter P. Siegmund eds., 2007) (discussing the difficulties of testing automotive protective equipment).

197. *See* Suanez v. Egeland, 801 A.2d 1186, 1193 (N.J. Super. Ct. App. Div. 2002) ("The only specific scientific tests to which Thibault referred were performed either upon cadavers or upon military personnel under controlled conditions . . . ."); *see also* Hisenaj v. Kuehner, 903 A.2d 1068, 1074 (N.J. Super. Ct. App. Div. 2006), *rev'd*, 942 A.2d 769 (2006) (noting that the biomechanical engineer had "conducted experiments with cadaver parts, determining the strength of various materials making up the musculoskeletal system").

198. *See, e.g.*, *Suanez*, 801 A.2d at 1193 (referencing tests on military personnel under controlled conditions).

199. *See* W. N. Newberry et al., *Analysis of Acute Mechanical Insult in an Animal Model of Post-Traumatic Osteoarthrosis*, 120 J. BIOMECHANICAL ENGINEERING 704, 704–06 (1998) (using rabbits to study the effect of chronic degeneration of cartilage and bone after exposure to forces exceeding a threshold of injury); *see also* Liying Zhang, King H. Yang & Albert I. King, *A*

attempt to match those tests with observations of trauma victims in the general population.[200]

Another way of gathering data for an injury threshold is to outfit a group of subjects with accelerometers, subject them to traumatic forces, and "normaliz[e] the injury incidence data by the . . . exposure data."[201] Importantly, biomechanical engineers gathering data typically rely on medical doctors to determine whether subjects were actually injured during the test and what injuries were sustained.[202] Some injury thresholds are relatively well-established in the field of biomechanics and have been used outside the litigation context.[203] Other thresholds are tentative.[204]

2. The Reliability of Injury Causation Opinions Based on Injury Thresholds

The reliability of a forensic biomechanical analysis depends on whether results of population-based studies can be extrapolated with accuracy to specific individuals and circumstances.[205] The practice of forensic epidemiology employs

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Proposed Injury Threshold for Traumatic Brain Injury, 126 J. BIOMECHANICAL ENGINEERING 226, 226 (2004) (noting that existing head injury criteria were based on "head acceleration results from animal concussion tests and cadaveric skull fractures").

200. *See* Augenstein & Digges, *supra* note 23, at 1–2 (discussing biomechanical engineer's collection of data gleaned from patients suffering traumatic injuries). For example, the N_{ij}, a neck injury criterion, was "originally derived from porcine neck testing" and was "then matched to injuries observed in real world non-rollover frontal crashes." Freeman & Kohles, *Forensic Biomechanics*, *supra* note 30, at 462.

201. *See id.* at 343–45, 356–57 (2007) (gathering head impact data from sixty-four football players over four years and proposing a modification to current mild traumatic brain injury risk curves).

202. *See id.* at 345 ("Impacts were classified as injurious based on a diagnosis of concussion by the team physician.").

203. *See* Hayes et al., *supra* note 33, at 58–60, 62–62 (discussing the Abbreviated Injury Scale (AIS), Head Injury Criterion (HIC), and the Neck Injury Criteria (NIC) and their uses).

204. *See* Funk et al., *supra* note 143, at 359 (noting that "50% risk levels for concussion cannot be calculated reliably because the exposure data are extremely sparse" and stating that proposed injury curves for concussion "are only a first attempt at calculating injury assessment risk values from limited injury data").

205. *See* Freeman & Kohles, *Forensic Biomechanics*, *supra* note 30, at 69

population-based data "as a basis for evaluating the consistency of findings in an individual case with what is plausibly associated with a particular injury mechanism."[206] The appeal of epidemiological evidence in personal injury cases is that it can be adapted easily to the 50%-plus probability standard familiar to courts.[207] A probability derived from epidemiological evidence is known as *relative risk*.[208] For purposes of illustration, imagine a box filled with balls. A sampling test shows that 60% are blue and the others are white. In this example, the relative risk that one will randomly select a blue ball from the box is 60%.[209] Once the ball has been selected, however, the relative risk does not matter because the ball is either blue or white.[210] Statisticians have commented that "there is no logically rigorous definition of what a statement of probability means with reference to an individual instance."[211]

a. Testability

Outside of litigation, injury risk curves can be tested and revised, at least in limited ways, by comparing predictions of injury based on biomechanical risk curves against actual injuries observed in subjects.[212] Some—if not most—forensic applications

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(discussing the difficulties of extrapolating from biomechanical literature to specific cases).

206. Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 459.

207. *Id.* at 611.

208. *See id.* (discussing the use of relative risk to make statements about the probability of individual causation). For a more thorough discussion of the role of relative risk in causation determinations, see Laubach, *supra* note 91, at 1036–39.

209. *Id.* at 611 n.188 (illustrating relative risk and describing frequentist statisticians' opposition to subjective probability statements).

210. *Id.*

211. Lee Loevinger, *On Logic and Sociology*, 32 JURIMETRICS J. 527, 530 (1992). The same principle is true in toxic torts, where the use of relative risk may be "misleading when a plaintiff has a genetic or epigenetic susceptibility to a particular substance." Laubach, *supra* note 91, at 1039.

212. *See, e.g.*, Funk et al., *supra* note 143, at 345 (testing and proposing modifications to an injury risk curve based on observations of injuries in a study and noting that "[i]mpacts were classified as injurious based on a diagnosis of concussion by the team physician").

of the three-step biomechanical analysis also rely on medical doctors' diagnoses to test the accuracy of the analysis.[213] Ironically, biomechanical experts in litigation regularly critique medical doctors' diagnoses.[214] But without deferring to medical doctors, there is no way to test the application of a biomechanical expert's forensic analysis. It is impossible to acquire samples of the materials at issue—the plaintiff's tissue or bones—to test the expert's method by calculating the plaintiff's true tolerance to injury.[215] A lack of ability to test the forensic biomechanical method weighs against the admission of specific injury causation opinions.[216]

b. Peer Review

Forensic biomechanical analyses have been used outside litigation to examine likely mechanisms of injuries in deceased subjects,[217] and to opine whether safety features such as seat belts might have mitigated injuries.[218] These studies often use the three-step analysis used by biomechanical experts in litigation.[219] Very few or none of these studies, however, attempt to determine *whether* an individual was actually injured.[220]

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213. *See* ROBERT A. GALGANSKI ET AL., NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., CRASH VISUALIZATION USING REAL-WORLD ACCELERATION DATA 1 (2001) (comparing injuries in medical records with injury predictions based on computer simulations).

214. *See supra* note 17 and accompanying text (discussing biomechanical engineers' critiques of medical doctors' causation opinions).

215. *See supra* note 196 and accompanying text (discussing the impossibility of measuring or testing individual injury thresholds).

216. *See, e.g.*, Berry v. Crown Equip. Corp., 108 F. Supp. 2d 743, 754 (E.D. Mich. 2000) (noting that "courts interpreting *Daubert* have considered testability of the expert's theory to be the most important of the four factors").

217. *See* Ejlersen et al., *supra* note 31, at 464 (describing a joint medical and biomechanical investigation to discover traumatology and a potential cause of death).

218. *See* NAT'L TRANSP. SAFETY BD., *supra* note 23, at 15 (discussing the benefit of computer simulations created by biomechanical engineers of a school bus roll-over as a tool "to evaluate specific mechanical and biomechanical issues for similar types of accidents").

219. *See* Hayes et al., *supra* note 33 at 68–69 (citing peer-reviewed and published studies that employed the three-step analysis).

220. *See infra* notes 221–223 and accompanying text (discussing cases cited

Instead, these studies use the three-step analysis to predict the effect of seat belt use,[221] to show that computer simulations' predictions compare reasonably well to actual occupant dynamics and to injuries previously diagnosed by medical doctors,[222] or to predict whether proposed design and safety features in automobiles and aircraft might reduce the potential for human injury.[223] In these studies, the biomechanical analysis is not used to dispute the medical doctor's injury causation opinion but rather to explain how the trauma might have caused the injuries.[224] In other words, the three-step biomechanical analysis is used most often outside of litigation "*after* a causal determination has been made, as a means of explaining injuries."[225]

In sum, the three-step biomechanical analysis has been accepted by the biomechanical community and appears in peer-reviewed literature, but it has not been applied for the same purpose that it is being used in litigation.[226] This presents a

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by Wilson C. Hayes, Ph.D., as supporting the three-step analysis as a method for determining specific injury causation).

221. *See* NAT'L TRANSP. SAFETY BD., *supra* note 23, at 15 (discussing the benefit of computer simulations created by biomechanical engineers of a school bus roll-over as a tool "to evaluate specific mechanical and biomechanical issues for similar types of accidents").

222. *See* Kennerly H. Digges, *Reconstruction of Frontal Accidents Using the CVS-3D Model*, SAE TECH. PAPER 840869, Apr. 1, 1984, at 1–2 ("The results computed by the model are quite reasonable when compared with the injuries received by the occupant."); C. Clark, *Simulation of Road Crash Facial Lacerations By Broken Windshields*, SAE TECH. PAPER 870320, Feb. 23, 1987, at 1–3 ("The physical simulations approximated the damage observed in the three accidents.").

223. *See* L. Obergefell, *Computer Simulation Of Human Body Dynamics*, 2 J. GRAVITATIONAL PHYSIOLOGY 92, 92–93 (1995) (noting the usefulness of this methodology in testing safety features due to the constraints in testing actual human subjects); NAT'L TRANSP. SAFETY BD., 15-PASSENGER CHILD CARE VAN RUN-OFF-ROAD ACCIDENT MEMPHIS, TENNESSEE 45–46 (Apr. 4, 2002) (using biomechanical principles and computer simulations to conclude that the use of a different vehicle and the proper use of child restraints could have mitigated injuries in a crash).

224. *See* Ejlersen et al., *supra* note 31, at 463–65 (describing a biomechanical analysis as an adjunct to a medical investigation regarding traumatology and cause of death in an individual).

225. Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 460 (emphasis in original).

226. *See supra* notes 222–225 and accompanying text (collecting studies

danger that biomechanical experts' specific causation opinions are based on a method that does not justify their conclusions.[227]

c. Error Rate

The second step of the three-step analysis is the only method that has published error rates.[228] Courts should avoid conflating the error rates of computer simulations with biomechanical experts' methods of predicting injury. Because there are no published error rates for the other methods in the three-step biomechanical analysis, courts should consider implicit error rate issues, including validity, specificity, and accuracy.[229]

Regarding validity, inferences drawn from experimental studies "are justified only when the sample is representative."[230] The subjects of biomechanical studies are often not representative of the larger population.[231] The confidence in an extrapolation from biomechanical studies to a different population—let alone a unique individual—is low because biomechanical engineers cannot quantify "outside factors that would or would not affect the outcome,"[232] such as pre-existing injury, lifestyle, age, sex, and other factors.[233]

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employing the three-step biomechanical analysis and describing the purposes of those studies).

227. *See* Meixner & Diamond, *supra* note 65, at 1090 (noting that experts err when they "base[] an opinion on some scientifically derived data, but those data could not justify the conclusion that was drawn").

228. *See supra* note 178 and accompanying text (listing published rates of error for computer simulation programs).

229. *See* Meixner & Diamond, *supra* note 65, at 1067 (stating that where numerical error rates are unavailable, "the judge must examine the methodology for flaws that are likely to produce errors").

230. DAVID L. FAIGMAN ET AL., *supra* note 84, § 6:8.

231. *See infra* notes 272–273 and accompanying text (discussing the inability of biomechanical studies to contain the quantity and types of subjects or conditions that reflect those seen in the real world).

232. DAVID L. FAIGMAN ET AL., *supra* note 92, § 23:18.

233. *See* Eskin v. Carden, 842 A.2d 1222, 1229 (Del. 2004) (stating that "[t]he use of applied physics by trained engineers aided by computer simulations . . . does create indicia of reliability" but that "[i]f the crash test dummy or a member of the control group is replaced with an uniquely susceptible driver, those indicia of reliability become a facade").

Forensic biomechanical methods may also lack specificity because many injury risk curves are based on anatomical regions and do not distinguish between specific injuries. For example, the Head Injury Criterion "does not distinguish among types of head injuries such as skull fractures, subdural hematoma, [or] diffuse axonal injury."[234] In addition, the computer simulations used by biomechanical engineers can only estimate forces applied to anatomical regions (represented by ellipsoids) instead of specific anatomic structures.[235]

With regard to accuracy, relative risk calculations are known to result in false positives and false negatives. For example, researchers who proposed a risk curve for mild traumatic brain injury observed that one of the subjects suffered a concussion after a hit generating forces below the proposed 1% mark, while some sustained much higher impacts without injury.[236] The researchers stated that "[t]he variation in injury tolerance between individuals explains why high severity impacts cause [mild traumatic brain injury] in some players but not others."[237]

In another context, biomechanical engineers hired by the National Transportation Safety Board to analyze school bus crashworthiness gathered data and simulated bus accidents using five different computer programs.[238] The biomechanical engineers compared predicted injuries against actual injuries sustained.[239] The biomechanical experts' methods failed to predict the actual injuries sustained by two of six occupants analyzed in one crash, and predicted thorax injuries for a third occupant who,

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234. Steven C. Batterman & Scott D. Batterman, *Forensic Engineering and Science*, *in* FORENSIC SCIENCE AND LAW: INVESTIGATIVE APPLICATIONS IN CRIMINAL, CIVIL, AND FAMILY JUSTICE 566 (Cyril H. Wecht & John T. Rago eds., 2006).

235. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 466 ("[A] precise or even rough estimate of the magnitude, direction, and rate of load sustained at a given disk level may be virtually impossible to determine given the number of unknown variables required to accurately reconstruct the intraspinal loads induced by the collision.").

236. *See* Funk et al., *supra* note 143, at 350 (reporting study results).

237. *Id.* at 358.

238. *See* NAT'L TRANP. SAFETY BD., HIGHWAY SPECIAL INVESTIGATION REPORT: BUS CRASHWORTHINESS 5–6, 15–16 (Sept. 21, 1999) (stating the goals of the research and explaining the simulation methodology).

239. *See id.* at 23 tbl.3 (comparing actual and predicted injuries).

in reality, suffered no injury.[240] These are only a few examples of the inaccuracy of relative risk opinions.[241] Yet without an error rate, one has no way of understanding how often a biomechanical analysis will produce a false positive or negative.[242]

In sum, considerations of validity, specificity, and accuracy weigh against the reliability of the three-step analysis when used as evidence of specific injury causation. The three-step analysis is capable of calculating relative risk of injury based on proposed thresholds, but its ability to predict the actual outcome is suspect.[243] These considerations weigh against the reliability of specific causation opinions and support scientists' arguments that relative risk should play "a highly circumscribed role in evaluating causation."[244]

d. Advisory Committee Notes Factors

This Subsection applies the five considerations in the Advisory Committee notes to Rule 702 in the order they are listed in Part III.B.2.[245] First, a biomechanical engineer is most likely to testify about matters growing out of research independent of litigation when he or she testifies regarding injury causation generally. Some biomechanical experts have conducted experimental tests related to injury thresholds or injury

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240. *See id.* (same).

241. *See* Allan F. Tencer et al., *Femur Fractures in Relatively Low Speed Frontal Crashes: The Possible Role of Muscle Forces*, 34 ACCIDENT ANALYSIS PREVENTION, 1, 7 (2002) (listing femur fractures suffered at forces supposed to have only a 17% to 27% probability of injury according to biomechanical thresholds); Batterman & Batterman, *supra* note 234, at 566 ("[I]t is possible for a person to walk away uninjured from an accident with an HIC greater than 1000 while a person can die from a head injury in a crash where the HIC was significantly less than 1000.").

242. *See* Freeman & Kolhes, *Forensic Biomechanics*, *supra* note 30, at 70 (examining problematic error rates in forensic biomechanics analyses).

243. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 467 ("Forensic biomechanical analysis is a useful adjunctive tool in forensic medicine, however limitations in its use must be acknowledged and heeded, otherwise the potential for erroneous application arises.").

244. *Id.* at 459.

245. *See supra* note 64 and accompanying text (listing considerations for reliability included in the Advisory Committee notes to Rule 702).

mechanics.[246] These studies, however, are population-based. Unlike medical doctors, biomechanical engineers outside of litigation do not determine whether or not a specific incident actually caused an individual's injuries, except when a biomechanical analysis is an adjunct to medical studies.[247]

Second, there is a danger of unjustifiable extrapolation because injury risk curves were originally developed to help designers "create equipment, rules, and operating procedures" that reduce the risk of injury, not as a means of judging whether a specific trauma was the cause of an individual's injuries.[248] The risk of unjustified extrapolation is at its highest when biomechanical engineers extrapolate general data to plaintiffs and circumstances dissimilar from the test subjects and circumstances in the biomechanical literature.[249]

Third, biomechanical engineers cannot identify or rule out other obvious causes of injury because they lack the medical expertise to identify pre-existing injuries and diseases that can contribute to or cause injury.[250]

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246. Stedman v. Cooper, 292 P.3d 764, 766 (Wash. App. 2012) (noting that a biomechanical expert had received government grants to research mechanisms of cervical injuries and that the expert had conducted tests aimed at developing improved car seat head restraints for prevention of impact injuries).

247. *See, e.g.*, Ejlersen et al., *supra* note 31, at 463–65 (describing a joint biomechanical analysis adjunct to a medical investigation of traumatology and cause of death).

248. Charles F. Babbs, *A New Biomechanical Head Injury Criterion*, 6 J. MECHANICS MED. & BIOLOGY 349, 350 (2006); *see also* Batterman & Batterman, *supra* note 234, at 565–66 (explaining that injury thresholds entered the law when the National Traffic and Motor Vehicle Safety Act of 1966 introduced the concept of vehicle crashworthiness and required designers to comply with certain injury criteria); Schultz v. Wells, 13 P.3d 846, 852 (Colo. App. 2000) ("[T]he court questioned the validity of using a series of tests designed for one purpose (designing cars) for a different purpose (assessing a threshold of applied force for injury in rear-end car accident).").

249. *See* Tittsworth v. Robinson, 475 S.E.2d 261, 263–64 (Va. 1996) (excluding biomechanical expert testimony where there was "no proof that these experiments were conducted under circumstances substantially similar to those existing at the accident scene").

250. *See* Eskin v. Carden, 842 A.2d 1222, 1231 (Del. 2004) (finding Lawrence Thibault, D.Sc. incompetent to take into account a plaintiff's pre-existing condition and proclivity to further injury where he did not review medical records or examine the plaintiff and stating that no evidence suggested "that any expert in his field would be competent, or would have taken the opportunity to do so").

Fourth, there is a danger that biomechanical experts employed as litigation consultants do not employ the same rigor as biomechanical researchers in the field.[251] For example, biomechanical experts typically rely on a single simulation attempt to show the way an accident occurred, while researchers in the field use a range of studies to account for missing variables, use multiple computer programs to verify simulation results, or at least make known the assumptions and limitations of their methodologies.[252]

Fifth, the biomechanical field is relied upon outside of litigation to predict injury in populations, not in individuals.[253] In addition, there is no consensus in the field of biomechanics that injury thresholds reliably measure actual injuries,[254] especially under circumstances different than the test circumstances.[255] These factors also weigh against the reliability of biomechanical experts' specific causation opinions when based on the three-step forensic biomechanical method.

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251. *See* Plaintiffs' *Daubert* Motion, *supra* note 1, at xv

> I'm being asked here to render an opinion whether a singular event caused a set of alleged injuries in a particular person. That is generally not the intent of the papers that I have either submitted, or I have served as the editor of a journal and reviewed literally thousands of them. It's a different setting entirely.

252. *See* NAT'L TRANSP. SAFETY BD., *supra* note 23, at 16–17, 80–81 (noting that researchers used two computer simulation programs and listing the researchers' data input assumptions and the limitations of their computer simulations).

253. *See id.* at 23 tbl.3 (acknowledging discrepancies between predicted and diagnosed injuries and relying on medical diagnoses as the actual injuries suffered by the occupants).

254. *See* Schultz v. Wells, 13 P.3d 846, 852 (Colo. App. 2000) (noting a trial court's finding that there "is great controversy in the field about the quality and comparability of [biomechanical] tests" (internal quotation marks omitted)); Wach & Unarski, *supra* note 25, at 136 (explaining that, although biomechanical literature on falls is extensive, it is concerned primarily with statistical data which "are not directly applicable in individual cases").

255. *See* Freeman & Kohles, *Forensic Biomechanics*, *supra* note 30, at 462 (noting that the Nij risk curve was "originally derived from porcine neck testing" and "has not been validated for injury mechanisms outside of frontal traffic collisions"; therefore, "any use of the metric for other injury mechanisms should be approached with caution").

3. The Reliability of General Injury Causation Opinions

General causation opinions are more directly related to the biomechanical literature, require less extrapolation, and better reflect biomechanical opinions offered outside of litigation.[256] Biomechanical expert testimony that claims to rule out the possibility of injury in any human at a given force, however, raises special reliability concerns.[257]

a. Opinions Ruling Out Causation Based on "Activities of Daily Living" Theories

For some parts of the body, such as arteries, no injury threshold has been proposed.[258] When no published threshold exists, some biomechanical experts have testified that forces associated with "activities of daily living" can substitute as a threshold below which no injury to any anatomic structure is likely.[259] Researchers have measured forces associated with coughing, stepping off a curb, skipping rope, and lifting.[260] Some researchers have attempted to bolster the "activities of daily

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256. *See, e.g.*, Wilcox v. CSX Transp., Inc., No. 1:05-CV-107, 2007 WL 1576708, at *12 (N.D. Ind. May 30, 2007) (allowing general causation opinions and noting that the plaintiffs conceded that biomechanical engineers may be qualified to testify to risk factors in general).

257. *See infra* Part V.C.3.a (discussing the weaknesses of opinions ruling out causation).

258. *See* Plaintiffs' *Daubert* Motion, *supra* note 1, Exhibit A at 22 (recording the following statement made by Wilson C. Hayes, Ph.D. in response to a deposition question regarding the existence of an arterial injury threshold: "At the level of forces necessary, I don't know, and believe no data are available").

259. *See id.* at 31–32 ("[I]f the forces are well within activities of daily living, our literature tells us, basically, you can't establish that the event caused the injury."); Schultz v. Wells, 13 P.3d 846, 850 (Colo. App. 2000) (noting proffered biomechanical evidence "related to the results of automobile collision experiments with human volunteers; specifically, the resulting threshold of force below which a person probably could not be injured in a rear-end automobile collision").

260. *See Schultz*, 13 P.3d at 852 (listing "activities of daily living" used by a biomechanical expert to support his causation opinion); *see also* James R. Funk et al., *Head and Neck Loading in Everyday and Vigorous Activities*, 39 ANNALS BIOMEDICAL ENGINEERING 766, 767 (2011) (collecting data from activities, including soccer ball impact, self-imposed hand strike to the forehead, chair tip, "chair plop," vigorous head shake, seated drop, and jump off a step).

living" threshold with bumper car experiments and low speed crash tests.[261] One prominent biomechanical expert has testified that "if the forces are well within activities of daily living, our literature tells us, basically, you can't establish that the event caused the injury."[262] This type of opinion attacks a criterion of general causation known as *plausibility*.[263]

(1) Problems with Establishing Implausibility

The first problem with this type of opinion is the misuse of the "plausibility" criterion. An injury is plausible when an exposure "*could* reasonably have caused the disease or injury outcome (regardless of how often)."[264] Biomechanical engineers' attack on the link between low-level force and injury commits the "fallacy of the transposed conditional by concluding that the absence of evidence of biomechanical plausibility of causation is equivalent to evidence of implausibility."[265]

In reality, plausibility "is met when there is a *lack of established implausibility* (impossibility)."[266] Therefore, "[r]arity is not the same as implausibility."[267] Anecdotal evidence of injuries sustained at low levels of force supports an inference that injury at low levels of trauma does occur, although rarely.[268]

Implausibility is only established when a theory of injury causation violates a fundamental biologic principle that is

261. *See* VINOD VIJAYAKUMAR ET AL., HEAD KINEMATICS AND UPPER NECK LOADING DURING SIMULATED LOW-SPEED REAR-END COLLISIONS: A COMPARISON WITH VIGOROUS ACTIVITIES OF DAILY LIVING 2 (2006) (comparing head kinematics in bumper car collisions with low speed vehicle collision data in the biomechanical literature).

262. Plaintiffs' *Daubert* Motion, *supra* note 1, Exhibit A at 22.

263. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 463–64 (discussing biomechanical engineers' use of Bradford Hill criteria with respect to general injury causation).

264. *Id.* at 463 (emphasis in original).

265. *Id.* at 459 (internal quotation marks omitted).

266. *Id.* at 462 (emphasis in original).

267. *Id.*

268. *See, e.g.*, Doré DeBartolo, *A Case of Cauda Equina Syndrome Caused by a Simple Sneeze*, 3 OSTEOPATHIC FAM. PHYSICIAN 27, 27 (concluding that a sneeze was the inciting event for nerve compression in the spine of a patient with pre-existing lumbar spine conditions).

universally accepted and incontrovertible.[269] One example is the principle that trauma cannot cause "brain tumors to appear spontaneously overnight."[270] The body of "activities of daily living" studies is not substantial and convincing enough to establish implausibility.[271]

(2) The Validity and Sufficiency of "Activities of Daily Living" Studies

Most "activities of daily living" studies include between twenty and thirty subjects, suggesting that the studies may not have sufficient statistical power to exonerate a link between low-level trauma and injury.[272] These studies usually exclude subjects with pre-existing medical conditions or disease, as well as young and elderly subjects.[273] The studies therefore "cannot contain the quantity and types of subjects and conditions that sufficiently represent the range of variety seen in real world subjects and conditions."[274]

In addition, selection bias plagues these experimental studies.[275] True randomization is impossible because the subjects

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269. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 463 ("Implausibility is only established when cause and effect is ruled out because of the violation of a fundamental biologic principle . . . .").

270. *Id.*

271. *See* FAIGMAN ET AL., *supra* note 92, § 23:4 (noting that negative epidemiological evidence must be so strong that it cannot be rebutted by reliable and scientifically valid methodologies).

272. *See* Schultz v. Wells, 13 P.3d 846, 852 (Colo. App. 2000) (noting a trial court's finding that the statistical sample in tests used by a biomechanical engineer was "extremely low"); *see also* VIJAYAKUMAR ET AL., *supra* note 261, at 3 (conducting a study on thirty volunteer subjects); Funk et al., *supra* note 260, at 767 (conducting a study on twenty volunteer subjects).

273. *See* FEDERAL JUDICIAL CENTER, *supra* note 101, at 615 (discussing the problems of using probabilities when two agents may combine to increase the probability of causation).

274. Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 464; *see also* Batterman & Batterman, *supra* note 234, at 566 (noting that "normal biological variation across the population spectrum is not accounted for" in the research of injury thresholds).

275. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 464 (stating that the "effect of bias and scatter on the extrapolation of tolerance specifications" makes it difficult to establish implausibility with biomechanical experimental studies).

choose their own exposure rather than being randomly assigned to groups.[276] Researchers in this area typically do not select control groups, making it impossible to compare differences between individuals who were subjected (or subjected themselves) to trauma and those who were not.[277] In at least one of these studies, every test subject was an employee at a firm specializing in biomechanical forensics and consulting, and the subjects therefore may have had an interest in the outcome of the research.[278]

Finally, the authors of one study reported that up to half of the participants dropped out before the study was complete.[279] Researchers have failed to investigate whether those who decline to participate in these studies or drop out before its completion differ significantly from those who do not.[280] These deficiencies call into serious question the practice of generalizing the results of activities of daily living studies to populations and conditions outside the test subjects and circumstances.[281]

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276. *See* Funk et al., *supra* note 260, at 767 (noting that the volunteer test subjects could choose not to participate in any activity).

277. *See* Schultz v. Wells, 13 P.3d 846, 852 (Colo. App. 2000) (referencing a trial court's exclusion of a biomechanical expert's opinions in part because there were "no controls among and between the experiments with regard to age, physical conditions [and] actual position of the body" (internal quotation marks omitted)); *see also* FAIGMAN ET AL., *supra* note 84, § 6:9 ("[O]utcome figures from a treatment group without a control group generally reveal very little and can be misleading. Comparisons are essential.").

278. *See* Funk et al., *supra* note 260, at 767 (noting that all twenty volunteers were selected from a pool of employee-volunteers at the Biodynamic Research Corporation).

279. *See id.* (noting that the study included twenty volunteers, only ten of which completed all tests in the study).

280. FEDERAL JUDICIAL CENTER, *supra* note 101, at 584 (explaining the need for further investigation when those selected to participate decline or drop out to avoid selection bias).

281. *See* Freeman & Kohles, *Evaluation of Applied Biomechanics*, *supra* note 18, at 464 (stating that studies "of animal, cadaver, and human volunteer subjects produce results that describe only a part of the spectrum of injury response to a nearly infinite range and combination of injury scenarios in the real world").

b. Opinions Ruling Out Causation Based on Mechanisms of Injury

Similarly, negative evidence regarding mechanisms of injury is usually insufficient to rule out causation. It is common for a single type of injury to have multiple potential triggering mechanisms.[282] Mechanisms of injury based on researchers' observations depend on the accuracy of subjects' memory, and direct study of injury in live subjects is extremely limited by instrumentation technology and for ethical reasons.[283] As a result, the suspected mechanics of many injuries are tentative or inexhaustive.[284] In addition, biomechanical engineers frequently draw from medical literature to identify mechanisms of injury but are usually unqualified to rule out competing mechanisms of injury that involve disease or pre-existing conditions.[285] These considerations show that biomechanical literature on mechanisms of injury is typically not sufficient to rule out injury causation.[286]

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282. *See, e.g.*, DeBartolo, *supra* note 268, at 27–28 (stating that the most common cause of Cauda Equina Syndrome is midline disc herniation, but that other causes include spinal metastases, hematoma, epidural abscess, traumatic compression, acute transverse myelitis, spinal stenosis, tumor, ankylosing spondylitis, following traction or spinal manipulation, after epidural steroid injection, or as a post-operative complication).

283. *See* Kashiro Ono & Koji Kaneoka, *Motion Analysis of Human Cervical Vertebrae During Low Speed Rear Impacts by the Simulated Sled*, *reprinted in* HUMAN SUBJECT CRASH TESTING: INNOVATIONS AND ADVANCES 758–59, 757 (Lawrence S. Nordhoff Jr., Michael D. Freeman & Gunter P. Siegmund eds., 2007) (noting the supervision of an ethics committee and limiting sled testing to staged collisions at less than four miles per hour).

284. Yu Shao et al., *Blunt Liver Injury with Intact Ribs Under Impacts on the Abdomen: A Biomechanical Investigation*, 8 PLOS ONE 1, 1 (2013) ("[T]he hidden kinematic interactions between the liver and other abdominal organs are impossible to measure using standard biomechanical instrumentation. So the actual process and biomechanism of blunt liver injury still remain inexhaustive.").

285. *See* DeBartolo, *supra* note 268, at 27–28 (listing thirteen known mechanisms for Cauda Equina Syndrome, only a few of which involve direct trauma)

286. *See* Roach v. Hughes, No. 4:13-CV-00136-JHM, 2015 WL 3970739, at *12 (W.D. Ky. June 30, 2015) (excluding a biomechanical engineer's specific injury causation opinion that was based on the engineer's testimony that the "accident did not provide a mechanism to produce the brachial plexus injury described in [the plaintiff's] medical records").

VI. The Helpfulness and Relevance of General Causation Opinions

This Part applies the third prong of the *Daubert* analysis to biomechanical expert testimony. It discusses the helpfulness and relevance of general causation opinions in personal injury litigation and argues that otherwise admissible general causation opinions are not relevant in all cases and can be misleading and unfairly prejudicial when the plaintiff differs from test subjects in the biomechanical literature.

Biomechanical engineers' testimony regarding estimated forces in a collision may be helpful when the degree of trauma experienced is at issue in a case.[287] Many courts have taken the position that—at least as a matter of probability—there is "a correlation between the nature of the vehicular impact and the severity of the personal injuries."[288] Therefore, some courts have found that evidence concerning the severity of the impact is relevant despite the fact that some "very minor impacts lead to serious personal injuries, and vice versa."[289] This rationale, however, may not apply in cases where the plaintiff's injury could be caused at any level of trauma or could occur in the absence of trauma.[290]

Whether similar forces create a heightened risk of injury in the general population may be relevant in some cases, such as *Bowers*, where the mechanism of injury is not well understood.[291] In other cases involving traumatic injury, however, courts have found

287. *See* Schwartz v. Morrison, No. 12-CV-01001, 2013 WL 3216138, at *1 (D. Colo. June 25, 2013) (allowing a biomechanical engineer to testify regarding accident reconstruction and the effects a pre-existing spinal condition might have on the plaintiff's bodily movement during the accident, but not regarding the cause of the plaintiff's injuries); Granville v. Howard, No. 1 CA-CV 11-0133, 2012 WL 504197, at *3 (Ariz. Ct. App. Feb. 16, 2012) (stating that a biomechanical engineer "was not required to opine whether Granville was actually injured in order to assist the jury"); Schneider v. Chickadel, No. 02-1590-MPT, 2003 WL 21542318, at *1 n.2 (D. Del. July 8, 2003) (finding a biomechanical engineer's testimony "relevant only to the biomechanics of the accident").

288. Mason v. Lynch, 878 A.2d 588, 601 (Md. 2005).

289. *Id.*

290. For example, in Mrs. Crandall's case, medical literature stated that injury to the carotid artery could be caused by slight trauma or may occur spontaneously. Plaintiffs' *Daubert* Motion, *supra* note 1, at xvi–xix.

291. *See supra* note 135 and accompanying text (noting the need for general causation evidence in some cases where the mechanisms of injury are complex).

general or hypothetical causation opinions irrelevant and unhelpful,[292] misleading,[293] or even inappropriate attempts to bootstrap specific causation opinions.[294] General causation opinions run the risk of confusing the issues "by shifting the fact finders' attention from the particular to the universal."[295] General injury causation opinions, "while interesting, [are] irrelevant" because opinions based on biomechanical risk curves do not show whether or to what degree the plaintiff was in fact injured.[296] This is especially true when the plaintiff has pre-existing conditions or a special susceptibility to injury.[297]

Other courts have found general causation opinions relevant and helpful,[298] at least when the plaintiff has no special susceptibility to injury and is therefore more comparable to

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292. *See* Boyd v. CSX Transp., Inc., No. 2:08-CV-108-TLS, 2011 WL 854350, at *5 (N.D. Ind. Mar. 7, 2011) ("[T]he Defendant's presentation of Elaine Serina, a biomechanical ergonomics expert, is not helpful to the Court because her testimony only concerns whole body vibrations generally and not the specific injury and causation allegations in this case.").

293. *See* Schultz v. Wells, 13 P.3d 846, 852 (Colo. App. 2000) (finding it within the trial court's discretion to exclude two biomechanical engineers' opinions based in part on a finding that they would mislead the jury).

294. *See* Mason v. Rizzi, 89 A.3d 32, 38 (Del. 2004) (stating that "[i]t would have been inappropriate and unhelpful, we think, for the biomechanical expert's views about the effects of forces of impact upon people generally to be used as a basis to bootstrap a more particularized opinion" regarding the plaintiff's spine); Stedman v. Cooper, 292 P.3d 764, 764 (Wash. App. 2012) (affirming a trial court's exclusion of biomechanical engineering testimony as unhelpful where the expert claimed to give general causation opinions, but where "his clear message was that Stedman could not have been injured in the accident because the force of the impact was too small").

295. *Mason*, 89 A.3d at 37.

296. *See Stedman*, 292 P.3d at 768 (noting another trial court's exclusion of general causation opinions as irrelevant, and merely attempts to draw an inference to specific causation); *Schultz*, 13 P.3d at 851 ("The court assessed the usefulness of presenting a probability theory to the jury, and concluded that such testimony would be confusing and misleading to the jury.").

297. *See Mason*, 89 A.3d at 35 (reasoning that biomechanical opinions applying "activities of daily living" studies "would have resulted in juror speculation, confusion and unfair prejudice to Plaintiff" because the studies "were based on studies of normal spines").

298. *See* Ma'Ele v. Arrington, 45 P.3d 557, 560 (Wash. App. 2002) ("Dr. Tencer, a biomechanical engineer, testified that a crash like this one generally does not cause injuries. Tencer has extensively studied low-speed collisions . . . . The jury was entitled to believe Tencer over any of the other witnesses.").

subjects in the biomechanical literature.[299] The broad discretion given to trial courts on this issue leaves room for disagreement about the helpfulness of biomechanical experts' causation opinions based on the unique circumstances of each case.[300]

VII. The Role of Biomechanical Expert Testimony in Court

This Part proposes the scope of biomechanical expert testimony that should be admissible in typical personal injury litigation. It offers a roadmap for the application of *Daubert* in courts adopting either the *Smelser* or *Eskin* approach to biomechanical expert testimony.

First, where this is an issue of first impression, courts should adopt *Smelser*'s distinction between general and specific causation when considering the scope of biomechanical expertise.[301] This is appropriate because the field of biomechanics, like the fields of epidemiology and toxicology, is concerned with causality in populations.[302] Unless a biomechanical engineer has medical expertise, courts should limit biomechanical expert testimony to general causation opinions because biomechanical engineers do not possess the expertise to make individual assessments or adapt generalized data to unique individuals.[303]

General causation opinions include testimony that relates estimated forces of an accident to an injury threshold to show whether population-based evidence suggests a heightened risk of

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299. *See Mason*, 89 A.3d at 36 (noting in dicta that when a plaintiff is within a normal range, "no rational 403 analysis would likely result in a conclusion that the jury would be misled or confused").

300. *See* Stedman v. Cooper, 292 P.3d 764, 768 (Wash. App. 2012) ("The broad standard of abuse of discretion means that courts can reasonably reach different conclusions about whether, and to what extent, an expert's testimony will be helpful to the jury in a particular case.").

301. *See supra* notes 145–147 and accompanying text (discussing the reasons supporting the *Smelser* approach to limiting biomechanical expert qualifications).

302. *See supra* notes 98–103 and accompanying text (comparing the goals of experts in the fields of toxicology and biomechanics).

303. *See supra* notes 104–108 and accompanying text (collecting cases requiring medical expertise to offer specific causation opinions).

injury.[304] Specific causation opinions, on the other hand, focus on the nature and extent of the plaintiff's injury and whether the injury was or was not caused by the collision.[305]

In the event that a court adheres to the *Eskin* approach, a judge acting as gatekeeper should exclude opinions that concern the precise cause of a specific injury under *Daubert's* reliability prong.[306] Courts should consider the reliability of biomechanical analysis as three separate methodologies: (1) accident reconstruction; (2) computer simulation; and (3) extrapolation of population-based biomechanical studies to the facts of the case. The third step of this analysis is the most problematic, and it does not provide a reliable basis for reaching specific injury causation opinions because considerations such as testability, peer review, rate of error, and general acceptance weigh against the admissibility of these opinions.[307]

Next, general causation opinions that are most likely to fall within biomechanical expertise and to be reliable fall into two main categories: opinions regarding which of two competing traumatic mechanisms was more likely to cause a plaintiff's injury and opinions that the plaintiff's injury is consistent with injury mechanisms that have been observed to increase the risk of injury in populations.[308]

Courts should be wary of opinions claiming that causation is implausible based on "activities of daily living," mechanisms of injury, or other biomechanical studies.[309] Methodological weaknesses of "activities of daily living" studies make reliable extrapolations from these studies doubtful.[310] Current

304. *See supra* notes 110–122 and accompanying text (discussing the distinction between general and specific causation).

305. *See supra* notes 115–116 and accompanying text (discussing the distinction between general and specific causation).

306. *See supra* Part V.C (applying *Daubert's* reliability prong to biomechanical experts' methodologies and arguing that reliability considerations weigh against the admission of specific causation opinions based on forensic biomechanical methods).

307. *See supra* Part V.C (same).

308. *See supra* notes 114–115 and accompanying text (discussing the distinction between general and specific causation).

309. *See supra* Part V.C.iii (discussing the inability of current biomechanical literature to rule out causation in most cases).

310. *See supra* notes 272–281 and accompanying text (discussing the

biomechanical literature regarding a "no effect" threshold is insufficient to rule out causation as a matter of law, with a few narrow exceptions.[311]

Finally, general causation opinions may not be relevant in personal injury cases where the issue in dispute is the existence or severity of injury.[312] The likelihood that general causation opinions are irrelevant, confusing, misleading, or unfairly prejudicial is greatest when the plaintiff has a special susceptibility to injury or is otherwise unlike the test subjects of biomechanical studies.[313]

VIII. Conclusion

Over the past two decades, attorneys have retained biomechanical engineer experts in personal injury litigation with increasing frequency. Courts have disagreed about the scope of biomechanical expert opinions that are admissible under *Daubert*. This Note critically evaluates the application of the *Daubert* standard to biomechanical expert qualifications and methodologies. Biomechanical expert opinions are most likely to satisfy *Daubert* when addressing general aspects of causation. General causation opinions, however, are not always relevant or helpful in personal injury litigation. Therefore, this Note recommends a limited role for biomechanical experts in establishing or refuting injury causation.

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methodological weaknesses of studies supporting the "activities of daily living" threshold).

311. *See supra* Part V.C.iii (arguing that current biomechanical literature should only be sufficient to defeat claims of causation as a matter of law when the plaintiff's theory contradicts an incontrovertible biologic principle).

312. *See* Part VI (discussing the relevance of general causation opinions in personal injury cases).

313. *See supra* notes 292–297 (collecting cases that have excluded general causation opinions due to a risk of misleading or confusing the jury or because of unfair prejudice).