Journal of the National Academy of Forensic Engineers®

NATIONAL
ACADEMY OF
FORENSIC
ENGINEERS

http://www.nafe.org
ISSN: 2379-3252

Vol. XXIX No. 2 December 2012

Forensic Engineering Analysis in Injury Event Reconstruction and Causation Analysis: References to Activities of Daily Living

by William E. Lee III, Ph.D., P.E. (NAFE 655S)

Abstract

In the forensic engineering analysis of injury events (including event reconstruction and injury causation analysis), the forensic engineer often presents any associated forces in units of *g*'s. However, the ability of nontechnical individuals (including jurors) to accurately understand a given force in *g's* may be limited. One approach sometimes employed by forensic engineers to address this problem is to cite a number of so-called *Activities of Daily Living* (ADLs) along with their associated forces. Legal challenges to such citations are often based on an argument "it is confusing" in reference to jurors' ability to consider such information. Alternately, attorneys may argue that cited ADLs mislead the jury in that they may conclude that the presented ADLs somehow model the injury event under consideration (sometimes this is actually intended by the presenter). This manuscript will examine the use and potential misuse of ADLs. This will include a compilation of ADLs from credible sources. ADLs can indeed be useful to help others understand what a given force means via comparison to the forces associated with other hopefully familiar activities. The forensic engineer must be cognizant of the source of the ADL data, including both how and why the measurements were made. Most ADLs are not intended to somehow model a specific injury event, so the forensic engineer must exercise caution regarding this issue. Both appropriate and inappropriate applications of ADL citations will be discussed in detail, including actual case examples.

Key Words

Activities of Daily Living, injury event reconstruction, injury causation

Introduction

The understanding of an injury-related event (vehicular collision, slip-and-fall, falling objects, etc.) can be very complicated. In the legal realm, it is increasingly common for attorneys and others to retain the services of a forensic engineer with a specialty in injury biomechanics analysis. As such, the biomechanics expert's goal is to "assist the trier of fact to understand the evidence or determine a fact in issue.[1]" For reference, a biomechanics expert is an individual who is qualified to render opinions based on the application of biomechanics and related topics to the understanding of injury-related events. The biomechanics expert draws from physics, engineering, and biomedical science in order to understand how humans behave when exposed to various forces. The general protocol for an injury biomechanics

---

William E. Lee III, Ph.D., P.E., Dept. of Chemical & Biomedical Engineering, University of South Florida, Tampa, FL. 33620.

analysis can be found in the literature (reference 2 summarizes much of this literature). The qualifications of such an expert will not be addressed here; rather, the focus is on a specific approach often employed by biomechanical experts as part of their analysis and opinion presentation, i.e., the reference to Activities of Daily Living (ADLs).

The understanding of injury events usually references the associated forces. This may involve blunt trauma, i.e., the forceful contact of some object (intentional or accidental) with some part or region of a human body. The "object" may include vehicular interior surfaces (steering wheels, windshields, etc.), vehicular exterior surfaces (e.g., bumpers), walkway or floor surfaces, falling objects, or physical objects such as various solid objects (e.g., baseball bats) and even human hands or feet. Injury events may also relate to a particular acceleration history in the absence of any physical contacts (for example, "whiplash" injuries). In quantifying the amount of force that may be involved, the biomechanics expert may report his or her findings in units such as pounds of force or newtons. However, the use of *g's* is also commonly done since this focuses on the acceleration of the event relatively independent of the object mass. The use of *g's* has another advantage in that much of the literature on risk of injury increasingly uses *g's* to emphasize the importance of acceleration in understanding injury causation. Also, in the direct measurement of injury-related events (including general analysis, recreations and injury research), most of the measurement devices (e.g., accelerometers) provides the measurements in units of *g's*.

As a result, *g's* are commonly encountered as the "force" units in the forensic analysis of injury-related events. It should be noted that injury event reconstructionists (including vehicular collision analysis) routinely report accelerations in *g's*. This is true in injury biomechanics analysis as well. This reliance on *g's* has created a problem in the legal realm in that it is usually difficult for attorneys, jurors, and others involved in the litigation process (and even more broadly, the general public) to understand exactly what a given magnitude of *g's* means. With a poor understanding of *g's*, any subsequent analysis of an event involving force can be problematic.

One approach that is adopted by engineers, including both event reconstruction and injury biomechanics analysis, is to present a series of examples of *g's* that reference various ADLs. For example, if addressing an event associated with a 2 to 3 g exposure, the engineer presents a series of ADLs that encompass this 2 – 3 g range. On one level, this is done to assist in the understanding of what 2 – 3 g's mean. However, the ADLs that are referenced may introduce other issues, particularly does the cited ADL also serve as a model of the event in question. Thus the forensic engineer must understand the technical aspects of ADLs, why and how they were measured, and what concepts ADLs support (and what concepts are not supported). This is necessary to apply ADLs properly in a given analysis, i.e., to avoid possible mis-application, either unintentionally or intentionally.

Case study

Before exploring ADLs in depth, a typical injury biomechanics forensics situation that employs ADLs in the analysis will be presented. This illustrates a typical application and also introduces associated issues that may arise as a result of the application.

Case outline

An individual (the driver) is involved in a rear-end collision. This is a basic rear-end bumper-to-bumper collision with no offset or vehicle rotation. A soft tissue cervical injury is claimed. The injury biomechanics defense expert, in conjunction with an accident reconstructionist analysis, determines that the driver's head experienced 1.5 to 2 g average loading, oriented towards the rear of the vehicle. During the expert's testimony, he cites "plopping backwards into a chair" as a relevant activity of daily living. This activity, according to the expert, has a rear-directed acceleration of 5.6 g. The expert further argued: 1) this was an activity that everyone does; 2) the forces experienced by the claimant is well below this; and 3) the activity itself models a rear-end collision. Therefore, the claimant would not be expected to sustain any cervical injuries in the subject collision.

The plaintiff attorney argued that such references to activities of daily living would only confuse the jury as the basis for a motion that the defense expert testimony not be allowed. In rebuttal, the defense attorney argues that in the absence of such testimony, the jury has no idea as to how to interpret 1.5 – 2 g force. The plaintiff motion was overruled and the expert was allowed to proffer the testimony.

Case analysis

First, a more detailed analysis of the referenced ADL should be performed in order to better understand the relevance and accuracy of the ADL. The defense expert has sited one example of an ADL from a paper titled *Acceleration perturbations of daily living* by M.E. Allen and co-workers[3]. The stated objective of this 1994 journal article (it appeared in the respectable journal *Spine*) was to measure the forces of various ADLs and compare them to forces experienced in low velocity rear-end vehicular collisions. In the study protocol, eight "healthy" volunteers (4 males, 4 females) performed thirteen different activities while wearing a helmet instrumented with three bidirectional accelerometers. Each accelerometer could measure + 20 g with a sensitivity of 0.02 g. ADLs included coughing, hopping off a 20 cm step, and plopping backward into a chair (the data from this study is included in Table One). Focusing on "plopping backward into a chair", subjects were instructed to plop passively backwards into a low-backed office chair from a standing position. No information was provided as to chair construction, including any incorporated padding. The data from all subjects (who performed replicates) is summarized at right:

Rear-directed force:	low 1.8 g high 5.6 g mean 3.3 g
Vertical-directed force:	low 2.0 g high 8.5 g mean 4.4 g
Resultant of peak force (rear and vertical)	10.1 g oriented at 54.9 degrees (0^{o} is horiziontal)

The study reported that no significant forces were measured in the lateral direction. It is interesting to note that the calculated resultant force is based on the peak values rather than the means (which would have resulted in a 5.5 g force). This may reflect bias on the part of the authors, who may have an agenda item the discrediting of injury claims resulting from so-called low velocity rear-end collisions. This bias has been pointed out by other reviewers as part of a broader criticism that these ADLs in general do not model rear-end collisions (for example, see reference 4). Also, the study has a number of issues that should be considered such as: 1) only "healthy" young subjects were employed; 2) most of the ADLs were performed voluntarily, i.e., the subjects were very aware of what was going on; and 3) the influence of the helmet was not explored. In fairness to Allen and co-workers, most of the more virulent criticism has appeared in non-peer reviewed literature, with most of these appearing on web sites.

Returning to the case study, the defense expert chose to present the value of 5.6 g in his or her analysis as representing the forces associated with "plopping backward into a chair". This is a misrepresentation because the highest value was used, implying this was the mean value (which it clearly is not). Also, the expert ignored the vertical component. There is another more basic question: does "plopping backward into a chair" model a rear-end collision? Here, skepticism is warranted, noting: 1) the chair allowed more extension movement relative to a typical vehicle seat equipped with a head rest, designed to prevent significant head/neck extension movement in rear-end collisions; 2) head motion in both cases is not linear, but rather linear with angular motion (the overall head motions are still very different); 3) the time frame of a rear-end collision is typically significantly shorter; 4) the vertical component of the ADL measurements reflects significantly more vertical movement than that associated with a rear-end collision; and 5) the initial body positioning is totally different – in the ADL study, the subject is initially standing while in a rear-end collision, the subject is already sitting and typically restrained, with the back in close proximity to the seat back. In addition, subjects in the ADL study knew they were about to plop backwards whereas the typical victim of a rear-end collision does not know they are about to be impacted from the rear.

While not specifically addressed in the case study, clearly it would be incorrect to use other ADLs such as stepping off a curb as models of a rear-end collision. The error (whether intentional or not) arises when the expert employs language such as "the x g's experienced by the claimant during the event of interest is similar to the y g's associated with stepping off a curb (or some other ADL)". Anecdotal information from attorneys indicates this error is encountered frequently in expert testimony regarding personal injury cases.

In the case study, the plaintiff attorney expressed the concern that the use of ADLs in general would be confusing to a jury. Obviously, any analysis presented to a typical jury at Ph.D.-level mathematics and physics would be confusing (experts are sometimes guilty of this!). As indicated above, it is in fact misleading when an expert opines that some ADL models some specific injury event. However, it is a different issue when the goal is to help the jury understand what xx g's means in terms of activities they have performed in their daily lives (in the absence of the "modeling" issue). Here, ADLs may in fact assist the jury in understanding what xx g's mean. In the absence of such information, jurors may be vulnerable to improper interpretation of the force. For example, an attorney may say that 3 g's is THREE TIMES the force of gravity, presented with an emotional component that "this is a lot of g's". A skillful expert can present ADL information at a level where the jury "gets it". As such, the plaintiff attorney motion is unfounded. From my personal experience (other experts report the same outcome), judges have consistently ruled (in response to a challenge) that the use of ADLs to help the jury understand what xx g's mean is appropriate and admissible. It is when the ADL is further exploited as a model for some injury event that judges often rule the testimony is inadmissible.

It should be noted that the proper use of ADLs as discussed above is not limited to one side in a legal situation (i.e, solely a defense expert strategy). This approach can be effectively employed on behalf of both plaintiffs and defendants.

Another case example

A plaintiff is claiming low back injuries due to a sudden stop experienced while he was the sole occupant of an elevator that was descending three stories at a motel. He did not fall at any point, nor did he contact any of the elevator car walls. After the sudden stop occurred, the elevator resumed operation, arriving at the lobby level. Lobby cameras show the claimant leave the elevator and going to the motel front desk where he informed the clerk about the incident. The defense biomechanics expert, in tandem with an elevator technician and another mechanical engineering elevator expert, sought to recreate the incident by inducing sudden stops via all possible electrical and mechanical scenarios that could be identified. An accelerometer device was used to measure elevator car accelerations in all three dimensions. Repeated measures for all the identified sudden stop scenarios indicated that the highest deceleration was in the range 1.3 to 1.4 g's, with the "jerk factor" (basically the rate of z-direction acceleration da/dt) was just over 1.5 m/s^3. The plaintiff's attorney objected to the defense expert citing ADLs that focused on vertical forces such as stepping off a curb or a stair of various heights and other literature measurements of elevator accelerations. Ruling in the expert's favor, the judge determined that such references would be useful to the jury in understanding what 1.3 – 1.4 g's meant. The case resulted in a defense verdict.

ADLs from the literature

Selected ADL research from the literature is summarized in Tables 1-3. Table 1 summarized information from studies that focused on force measurements at the head level. Table 2 addresses studies that focused on the lower back (lumbar) region and Table 3 presents information that is not body region specific. Only studies where the forces were measured in g's are included. Other literature studies may measure forces in terms of pounds force or newtons (for example, shoulder and knee biomechanical studies usually adopt this convention); such studies are not included in this compilation. Also, only ADL measurements reported in journals, technical meetings, or research documents (such as a graduate thesis or dissertation) are included; information presented solely via a website are excluded.

Only general comments are included in the three tables. The original references will often present details regarding methodology, subject selection and tasks, and statistical analysis. As an observation, the rigor adopted in many of these studies in terms of proper experimental design, statistical issues, and the general description of what was done and why is highly variable and often minimal. Reference #4 explores this issue from more of a scientific viewpoint, citing several of the references included in this compilation.

Discussion

As discussed above, there are two objectives that can be adopted by forensic engineers employing ADL citations in their analysis. The first objective seeks to assist others (including juries) regarding the understanding of a given amount of g's in relation to some event of interest. The second objective attempts to use a specific ADL as a model of a specific injury event. The first objective can be employed by itself; normally, those who attempt the second objective also incorporate the first one. Pursuing the first objective can be very appropriate in many situations as long as the relevant information is presented in a clear and accurate way. As noted above, motions that challenge expert testimony that seeks to accomplish the first objective are routinely denied. It is clear that the second objective is very problematic, with significant difficulties in terms of the underlying science. Regarding expert testimony based on the second objective, Frye/Daubert challenges may be successful.

In understanding and employing a specific ADL in an analysis or presentation, the forensic engineer should have awareness of the following regarding the source of the ADL information:

- The purpose of the study
- Exactly how the activity was defined (when appropriate, what the subjects were specifically asked to do)
- Information on the participating subjects, including:
  - how many subjects were in the study
  - gender and age breakout
  - inclusion and exclusion criteria
  - subject awareness of the study objectives
  - how and where the subjects were recruited
- How the measurements were conducted (accuracy, precision, calibration, etc.)
- Study design itself (order of activities, replicates, etc.)
- Statistical analysis (including a discussion on variability)
- Appropriateness and objectivity of discussion and conclusions.

As noted earlier, many studies will show deficiencies in one or more of these areas. Also, it may be useful to note if there are any biases ("an agenda") present on the part of any of the investigators. This may apply to certain web sites that clearly have a position of advocating for a specific cause or position, potentially biasing any presented information. Finally, in a broader sense, it is important to note the quality of the source; peer-reviewed research is more credible than simple citation via a website.

When citing a specific ADL, the presenter should present the associated forces with a statistical awareness, i.e., cite mean values and indicators of variability (mean values, standard deviations, ranges, etc.). Also, the presenter should note that the reported values represent the responses of "screened" subjects that participated in the specific study. In other words, the forces experienced by other individuals for the same ADL may be below or exceed the reported values. Individual characteristics such as age, health status, physical limitations, use of assist devices, personality traits such as aggressiveness or cautiousness, etc. can influence what an individual might personally experience in terms of the specific ADL. In other words, each person is a unique individual. It is always a sound foundational basis for an analysis to proceed on an incident-specific and individual-specific situation assumption rather than a "one size fits all" basis.

It should be noted that the ability of the forensic engineer to cite ADLs in presenting expert opinions may vary from state to state. The use of ADLs has been consistently backed in the state of Florida (a Frye state). However, other states may have a legal environment where such ADL citations may not be permitted due to specific rulings that argue such citations due not satisfy Frye or Daubert criteria or are not allowed due to some other legal arguments.

Finally, it is important to reference the fact that the force of gravity is 1 g, not 0 g. Many lay individuals may be unsure as to this fact; some will argue that an individual is experiencing 0 g standing still since the individual is not moving. This is easily addressed as part of the expert's presentation of the analysis.

References

1. See Federal Rules of Evidence, Article VII. *Opinions and Expert Testimony*, particularly Rule 702.
2. Lee, W.E. III. Forensic engineering case analysis in biomedical engineering. J. NAFE.
3. Allen, M.E. *et al.* Acceleration perturbations of daily living: A comparison to "whiplash". Spine 19(11): 1285-1290, 1994.
4. McClune, T., Burton, A.K., and Waddell, G. Whiplash associated disorders: a review of the literature to guide patient information and advice. Emergency Medicine 19: 499-506, 2002.
5. Nauheim, R.S. *et al.* Comparison of impact data in hockey, football, and soccer. J. Trauma. 48(5); 938-941, 2000.
6. Nauheim, R.S. *et al.* Linear and angular head accelerations during heading of a soccer ball. Medicine and Science in Sports and Exercise 35(8): 1406-1412, 2003.
7. Lewis, L. H. *et al.* Do football helmets reduce acceleration of impact in blunt head injuries? Academic Emergency Medicine 8(6): 604-609, 2001.
8. Manoogian, S.J. Analysis of linear head accelerations from collegiate football impacts. M.S. thesis, Virginia Polytechnic Institute, 2005.
9. Pfister, B.J., Chickola, L. and Smith, D.H. Head motions while riding roller coasters: implications for brain injury. Am. J. Forensic Med. Pathol. 30(4): 339-345.
10. Khoo, B.C. *et al.* A biomechanical model to determine lumbosacral loads during single stance phase in normal gait. Med. Eng. Phys. 17(1): 27-35, 1995.
11. Cheng, C.K. *et al.* Influences of walking speed change on the lumbosacral joint force distribution. Biomed. Material Eng. 8(3-4): 155-165 (
12. M. Fehren *et al.* Loads on the lumbar spine during bungee jumping. 16th Symposium of the International Society of Biomechanics in Sports (July, 1998) www.isbs98.uni-konstanz.de.
13. Lee, W.E. III and Barnes, J.L. Activities of daily living: lumbar region measurements. Paper Presented at the BMES Annual Meeting, Sept. 26-29, 2007.
14. Science Net. The thrills and spills of g force. www.sciencenet.org.uk
15. Odgen, J.S. Forensic engineering analysis of damage and restitution in low velocity impacts. NAFE J. 11-34, December 1999.
16. Castro, W.H. *et al.* Do "whiplash injuries" occur in low-speed impacts? European Spine J. 6(6): 366-375, 1997.
17. Atha, J. *et al.* The damaging punch. British Medical J (Clin. Res. Ed.) 291(6511): 1756-1757, 1985.
18. Princemaille, Y. *et al.* Some new data related to human tolerance obtained from volunteer boxers. Proc. 33rd Stapp Car Crash Conf. 177-190, 1989 (SAE publication no. 892435).

Table 1
Activities of Daily Living: Measurements obtained in the head region

Activity	Associated forces	Reference	Comments
Look to left	0.3 g (0.1 – 0.6 g) horizontal 0.1 g (0.1 – 0.3 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Startle (unexpected starter pistol discharged behind subject)	0.5 g (0.2 – 0.7 g) horizontal 0.4 g (0.2 – 0.6 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Standing up (rising suddenly from a chair)	0.8 g (0.4 – 1.5 g) horizontal 0.9 g (0.6 – 1.2 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Sitting down (into a chair from standing position)	1.1 g (0.5 – 1.6 g) horizontal 1.0 g (0.4 – 2.0 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Sneeze (uninhibited sneeze after sniffing fine pepper)	1.0 g (0.7 – 1.5 g) horizontal 1.8 g (0.5 – 2.5 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Cough (simulated nonexaggerated cough)	1.1 g (0.5 – 3.0 g) horizontal 0.7 g (0.2 – 1.8 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Crowd josle (unexpected bump against posterior left shoulder	1.4 g (0.8 – 1.9 g) horizontal 1.8 g (0.7 – 3.0 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Slap on back (anticipated hardy greeting slap on left upper back)	1.7 g (0.5 0 2.7 g) horizontal 1.8 g (0.5 – 3.1 g) horizontal	3	Measured at head; mean value and range indicated (n = 8)
Chair kick (while seated, wheeled office chair kicked hard from behind)	2.1 g (1.0 – 3.7 g) horizontal 1.3 g (0.7 – 2.3 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Hop off step (hop off step, land on both feet)	20 2.7 g (1.3 – 4.5 g) horizontal 4.6 g (2.9 – 6.7 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Plop into chair (plop passively backwards into office chair)	3.3 g (1.8 – 5.6 g) horizontal 4.4 g (2.0 – 8.5 g) vertical	3	Measured at head; mean value and range indicated (n = 8)
Helmet hit, football (head-to-head hits)	29.2 g ± 1.0 g	5	Mean value ± standard deviation (n = 2 subjects, 132 contacts)
Helmet hit, hockey (head-to-head hits)	35.7 g ± 1.7 g	5	Mean value ± standard deviation
Soccer (ball heading, players wearing helmet)	54.7 g ± 4.1 g	5	Mean value ± standard deviation, ball average velocity 39.3 mph
Soccer (ball heading, players wearing helmet)	16.2 g ± 2.9 g (20 mph ball) 20.3 g ± 2.8 g (26 mph ball)	6	Mean value ± standard deviation (ball speed: 20 to 26 mph) 4 subjects, multiple Headings
Soccer (ball heading player unhelmeted)	19.2 g	7	Mean value, 3 subjects, multiple hits
Football helmet hits Defensive linemen (n = 6) Linebackers (n = 9) Running backs (n = 7) Defensive backs (n = 5)	 13.9 g 19.0 g 13.4 g 13.0 g	8	Mean value; multiple hits; helmet-to-helmet hits
Roller coasters (3 different rides)	5.4 – 10.2 g	9	Range of values, 4 subjects, multiple readings
Pillow fights	4.7 – 10.5 g	9	Range of values, 3 subjects, multiple hits

Table 2
Activities of Daily Living: Measurements obtained in the lumbosacral region

Activity	Associated forces	Reference	Comments
Walking (normal level walking)	1.45 – 2.07 g	10	Measured within the lumbo-sacral region; mean peak values are shown.
Walking (level, various speeds)	2.28 g (slow walking) 2.53 g (preferred speed walking) 2.95 g (fast walking)	11	Measured within the lumbo-sacral region; mean values are shown.
Trampoline jumping	5.8 g (vertical) (novices) 8.7 g (vertical) (competitors)	12	Lumbar region mean values shown (n = 5 in each group)
Normal level walking	1.4 g (1.0 – 2.4 g) (vertical component)	13	L5/S1 measurements; mean value and range given; n = 10 (athletic shoes, linoleum floor)
Speed level walking	1.7 g (1.2 – 1.6 g) (vertical component)	13	L5/S1 measurements; mean value and range given; n = 10 (athletic shoes, linoleum floor)
Jogging in place	4.7 g (2.0 – 10.9 g) (vertical component)	13	L5/S1 measurements; mean value and range given; n = 10 (athletic shoes, linoleum floor)
Trampoline jumping	5.7 g (2.6 – 8.4 g) (vertical component)	13	L5/S1 measurements; mean value and range given; n = 10
Jumping jacks	6.3 g (2.2 – 8.7 g) (vertical component)	13	L5/S1 measurements; mean value and range given (athletic shoes, linoleum floor)
Elevator ride (starts/stops)	1.1 g (1.0 – 1.1g) (vertical component)	13	L5/S1 measurements; mean value and range given
Jogging on treadmill (medium speed)	4.7 g (1.5 – 9.5 g) (vertical component)	13	L5/S1 measurements; mean value and range given
Stepping off 15.24 cm step	3.5 g (1.0 – 9.0 g) (vertical component)	13	L5/S1 measurements; mean value and range given
Stepping off 45.72 cm step	3.5 g (1.0 – 9.0 g) (vertical component)	13	L5/S1 measurements; mean value and range given

Table 3
Activities of Daily Living: Other measurements

Activity	Associated forces	Reference	Comments
Vehicle acceleration Porsche 0–60 mph/4 sec Drag racer 0–120 mph/4 sec)	 0.6 g 1.3 g	14	
Braking to a stop	0.6 – 0.8 g	15	
Driving over a curb	0.3 – 1.5 g	15	
Bumper cars	2.2 g (1.8 – 2.6 g)	16	Mean value and range; 4 subjects, multiple hits
Boxing punch (professional boxer punching an instrumented plate)	53 g	17	Mean value (multiple punches) mean velocity of fist: 20 mph
Boxing punch	18 – 79 g	18	Range of values