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3D-Printed Prostheses and Early Modern Iron Hands: A Method to Investigate the Lived Experiences of Amputees in the Premodern World

HEIDI HAUSSE AND CHAD G. ROSE

SUMMARY: This article advances a method developed by a historian and a mechanical engineer to learn about premodern amputees. Using a sixteenth-century iron hand from Germany as a foundational case study, the authors illustrate four components of an experimental approach for investigating fragile artifacts of prostheses. First, they present the creation of historically contextualized activities of daily living (ADLs), a concept used in modern prosthesis usability assessments. Second, the authors address the use of computer-aided design (CAD) and 3D printing technology to develop models of artifacts collaboratively. Next, they explain the significance of engaging with external interlocutors with crucial perspectives on disability advocacy and inclusivity. Finally, the authors suggest how to design experiments with ADLs to test 3D-printed models. Together, these components create a physical object and material encounters that can push exploration of prosthetic artifacts—one of the few direct sources of premodern amputees' lived experience—into a new frontier of research.

KEYWORDS: amputee, prosthesis, iron hand, 3D printing, 3D model, additive manufacturing

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Sitting largely unnoticed in a military-history exhibit in Bad Wildungen, Germany, is a sixteenth-century mechanical iron hand—the so-called "Kassel Hand" (Figure 1). Mechanical hands were a prosthetic technology that first appeared in the late fifteenth century.[1] The Kassel Hand's barrel-shaped fingers with engraved fingernails move through interior spring-driven mechanisms that still function. Its unknown user operated it by pressing down on the artificial fingers to lock them into position and freed them via a release at the wrist. Like other prostheses from this period, the Kassel Hand presents a tantalizing mystery. Was it easy to use, an aid for everyday tasks? Or was this an impractical device whose greatest value resided in the impression it made upon others? What can this object tell us about its wearer's experience?

Figure 1. Sixteenth-century right hand prosthesis made of iron in the collections of Hessen Kassel Heritage. Source: bpk Bildagentur / Antikensammlung / Museumslandschaft Hessen Kassel/ Kassel/Germany / Art Resource, NY.

[1] Heidi Hausse, *The Malleable Body: Surgeons, Artisans, and Amputees in Early Modern Germany* (Manchester: Manchester University Press, 2023), 155–209.

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Prosthetic artifacts like the Kassel Hand offer glimpses into the experiences, perspectives, and agency of premodern amputees, a group whose voices have long been missing in historical accounts. Premodern ego documents from amputees are scarce, and those that exist give little attention to the injured body, recovery, or how limb loss impacted everyday life.[2] This renders material culture a crucial form of evidence whose exploration has only begun among disability historians.[3] Surviving artificial limbs are rare and fragile. In 2013, a physical examination revealed that the Kassel Hand's fingers lock into seven positions. But testing—studying it through repeated movement, observing its ability to grasp objects, fastening it to a wearer—is not possible without risking damage.

This article advances a method to study premodern prostheses developed collaboratively by a historian and a mechanical engineer. We used the Kassel Hand as a foundational case study to create a framework that scholars of disability, medicine, technology, and material culture can adapt to investigate other historical prostheses. Our approach creates the conceptual and material tools needed to experiment with 3D-printed models of artifacts. This brings the humanities and sciences into conversation to reengineer a fragile object in a way that is economically feasible for researchers to pursue and accessible to the public once research is concluded.

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[2] E.g., Mareike Heide, *Holzbein und Eisenhand: Prothesen in der Frühen Neuzeit* (New York: Campus Verlag, 2019), 179; Bianca Frohne, "Performing Dis/ability? Constructions of 'Infirmity' in Late Medieval and Early Modern Life Writing," in *Infirmity in Antiquity and the Middle Ages: Social and Cultural Approaches to Health, Weakness and Care*, ed. Christian Krötzl et al. (New York: Routledge, 2016), 51–65.

[3] E.g., Nicole Belolan, "The Material Culture of Gout in Early America," in *Making Disability Modern: Design Histories*, ed. Bess Williamson and Elizabeth Guffey (London: Bloomsbury, 2020), 19–42.

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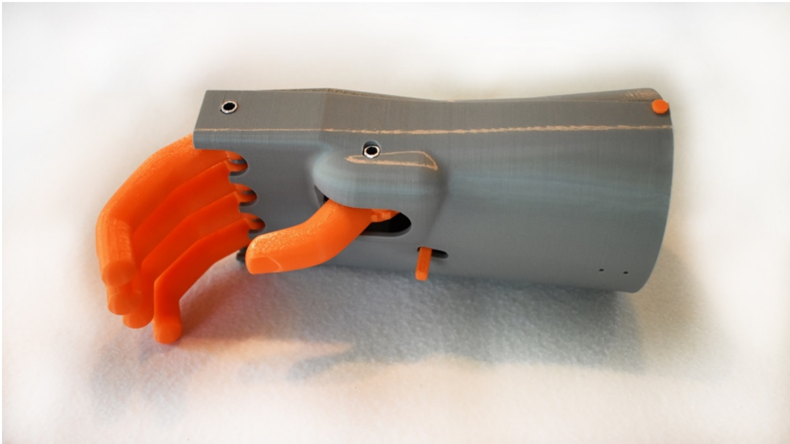

Figure 2. Kassel Hand Prototype 3.0, April 2025. Model by Heidi Hausse, Chad G. Rose, Peden Jones, Anakin Natter, and Stuart Simms. Source: Heidi Hausse.

A 3D-printed model of an artificial limb, such as our prototype of the Kassel Hand (Figure 2), offers historians a path forward in lab-based analyses of premodern prostheses. But for the model to have meaning and be used in a meaningful way, its creators must work with intention from start to finish. From May 2023 to May 2024, we developed four components to clarify and strengthen the relationship between an artifact and its model and to keep the historical wearer—the amputee—at the center. These combine disability scholars' commitment to building more inclusive communities with an empirical mode of inquiry found in archaeology and more recently advanced by historians of science. First is a theoretical component: the creation of historically contextualized activities of daily living (ADLs) to consider how an artifact may have been used. Next is a material component: building a model with computer-aided design (CAD) software and 3D printers. The third component is communal: holding conversations with others outside of the project who offer crucial perspectives on disability advocacy. Finally, the integrative component: designing experiments with information and materials developed through

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the first three. While no study can fully re-create the past, embarking on this fruitful process can help scholars learn more about the perspectives and experiences of premodern amputees.

Our method draws on several approaches to investigating the material past through replication and reconstruction.[4] Experimental archaeology offers lessons on documenting artifact reconstruction and at times employs 3D modeling.[5] Furthermore, its use of testing to study the functions of objects parallels our goals for experimentation.[6] However, using 3D printing and low-cost polylactic acid (PLA) plastics deviates from the archaeological tradition in a fundamental way: it does not use original materials or manufacturing processes. Creating an iron Kassel Hand replica using locksmithing and metalworking techniques, for example, would reproduce the very problem the original poses for testing—the prototype would be too precious to risk damaging. Moreover, it would remain just as inaccessible to other scholars and the public as the Kassel Hand itself.

The history of science provides further lab-based approaches.[7] Historians' experiments often focus on textual sources and, in the early modern context, recipes in particular.[8] Pamela H.

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[4] E.g., Sven Dupré et al., eds., *Reconstruction, Replication and Re-enactment in the Humanities and Social Sciences* (Amsterdam: Amsterdam University Press, 2020).
[5] E.g., Vibeke Bischoff, Anton Englert, Soren Nielsen, and Morten Raun, "From Ship-Find to Sea-Going Reconstruction: Experimental Maritime Archaeology at the Viking Ship Museum in Roskilde," in *Experiments Past: Histories of Experimental Archaeology*, ed. Jodi Reeves Flores and Roeland Paardekooper (Leiden: Sidestone Press, 2014), 233–48.
[6] John Coles, *Experimental Archaeology* (Caldwell: Blackburn Press, 1979; repr., 2010), 38–39.
[7] E.g., M. M. A. Hendriksen and Pamela H. Smith, "Material and Performative History of Science," in *Debating New Approaches to the History of Science*, ed. Lukas Verburgt (London: Bloomsbury, 2024), 213–38; Active Matter (https://activemattergroup.org).
[8] E.g., Hasok Chang, "How Historical Experiments Can Improve Scientific Knowledge and Science Education: The Cases of Boiling Water and Electrochemistry," *Sci. Educ.* 20 (2011): 317–41, here 318;

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Smith's influential Making and Knowing Project promoted reconstruction as method from its inception.[9] Concepts of "historical replication" and "physical replication" of scientific experiments, described as separate but equally valid forms of investigation, at times informed the project's use of different materials.[10] Historical replication uses original materials and procedures to reveal the "many-sided dimensions of natural sciences," including a deeper knowledge of the substances used and the laboratory spaces involved.[11] Physical replication, by contrast, works to re-create "the phenomena of interest" using any "convenient instruments and procedures."[12]

Making a 3D-printed model of a historical prosthesis engages with replication, reconstruction, and experimentation in complex ways. Creating the model itself occupies a space between the historical and the physical. It is not a historical replication because its primary focus is neither the object's makers nor the original process of making, but rather its wearer and how it was used *after* it was made. At the same time, it is not simply a physical replication using *any* convenient approach to re-create the prothesis's function. Our Kassel Hand model, for instance,

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Pamela H. Smith, *From Lived Experience to the Written Word* (Chicago: University of Chicago Press, 2022); William R. Newman, *Newton the Alchemist* (Princeton, N.J.: Princeton University Press, 2019).

[9] Pamela H. Smith and The Making and Knowing Project, "Historians in the Laboratory: Reconstruction of Renaissance Art and Technology in the Making and Knowing Project," *Art Hist.* 39, no. 2 (2016): 210–33, here 215.

[10] Caroline Marris and Stephanie Pope, "Sand Molds of Ox Bone, Wine, and Elm Root," in *Secrets of Craft and Nature in Renaissance France. A Digital Critical Edition and English Translation of BnF Ms. Fr. 640*, ed. Making and Knowing Project et al. https://edition640.makingandknowing.org/#/essays/ann_020_sp_15.

[11] Dietmar Höttecke, "How and What Can We Learn from Replicating Historical Experiments? A Case Study," *Sci. Educ.* 9 (2000): 343–62, here 358.

[12] Chang, "Historical Experiments" (n. 8), 320.

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attempts to accurately engineer the original's mechanisms. It is a historically grounded approximation of the features of the artifact that we intend to test.

Testing a model differs from historical or physical replications of scientific experiments because it involves creating *new* experiments to learn about how the artifact may have functioned. It attempts to establish the kinds of things a premodern prosthesis *could* do rather than reproduce what scholars already know it *did* do. Making a model, designing experimental assessments, and then running them are activities inextricably intertwined, yet distinct. Each moves further from what is known (the existence of the artifact) and toward what is *plausible* (how a wearer may have used it).

Still, our approach to investigating prosthetic artifacts has deep resonances with the paths historians of science have forged. Both are concerned with aspects of the past that can be more fully understood through active forms of inquiry. In the Making and Knowing Project, Smith focused on an "active dimension" of knowledge-making by re-creating practices.[13] Prosthetic limbs are active in a different way. They are designed to be worn and used. They play a role in how an amputee moves in spaces, interacts with objects, performs activities, and appears to others. As Katherine Ott describes modern limb prostheses, "These objects document movement."[14] Surviving prosthetic artifacts are profoundly out of context: they are in a different time and without a wearer, they are deteriorated, and they are static, on display or kept in storage. Finding ways to consider them in action—as objects of movement, as objects worn, as objects

[13] Smith, *From Lived Experience* (n. 8), 206.
[14] Katherine Ott, "Disability Things: Material Culture and American Disability History, 1700–2010," in *Disability Histories*, ed. Susan Burch and Michael Rembis (Chicago: University of Illinois Press, 2014), 119–35, here 121.

that inflect one's bodily encounter with the world—allows fuller consideration of their role in everyday life and, in turn, the everyday lives of their wearers.

The desire to re-create and test historical prostheses is not new. In 2008, Jacqueline Finch famously made replicas of two ancient Egyptian prosthetic toes that volunteer amputees wore to determine whether they were functional or cosmetic. Her work was akin to experimental archaeology in its attempt to imitate original materials, if not production techniques.[15] Our method departs from Finch's approach in three ways. First, we incorporate an investigation of the lived world of the original wearer in a way that she did not. Furthermore, whereas Finch's study began with the goal of seeking out volunteer amputees to wear the replicas, we recommend first inviting advocates and amputees to discuss whether and how to include amputees as participants. Finally, Finch's study created replicas that are themselves difficult for others to replicate. Our approach creates a model that can be shared digitally and 3D-printed by anyone.

Although museum scholars have developed thousands of open-access digital 3D models of various artifacts, printable and functioning 3D models of historical prostheses are—much like modern 3D-printed prostheses—a new frontier. Recently, a team of medical engineers at Offenburg University in Germany made 3D models and fabricated three premodern prostheses largely through polymer 3D printing: an artificial leg from ca. 300 B.C.E. Italy and two sixteenth-century artificial hands that purportedly belonged to Götz von Berlichingen.[16] Notably,

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[15] Jacqueline L. Finch, "The Significance of Two Ancient Egyptian Hallux Restorations to the History of Prosthetic Medicine: Evaluation of the Original Artefacts and the Biomechanical Assessment of Replicas" (Ph.D. diss., University of Manchester, 2009), 188–205.

[16] A. Otte, O. Weinert, and S. Junk, "3-D CAD-Rekonstruktion der ersten "Eisernen Hand" des Reichsritters Gottfried von Berlichingen (1480–1562): 1. Fortsetzung: Funktionsprüfung mittels 3-D Druck," *Arch. Kriminol.* 240 (2017): 185–92; Andreas Otte, "The Ancient Artificial Leg of Capua: First

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while this work drew on historical publications, it did not include historians or detailed examination of the artifacts. For example, one of their sources, a historian's diagram published in the 1980s, omitted occluded components and a mechanism to reset the fingers in a prosthetic hand. The team filled in those gaps, but did so without historical context.[17] Furthermore, examples of "everyday situation[s]" to assess the model's functionality included holding a mobile phone, an actively spraying garden hose, and the handle of a barbecue grill.[18] This reflected the team's interest in assessing the utility of historical prostheses for modern wearers. By contrast, our method seeks to gather historical knowledge about a prosthesis and its user.

Recent research illuminates the stakes of developing and disseminating this collaborative method. It is not simply the opportunity that 3D printing and prosthetics offer as a fecund area of overlapping interests between historians and STEM researchers, offering creative possibilities. It is also the stark reality that if historians remain on the sidelines, others will carry out this research without the benefit of their expertise to aim it toward making valuable insights into the past. In what follows, we lay out the four components of our method, illustrating each through our work with the sixteenth-century Kassel Hand. Our goal is to make this method accessible to other scholars. Though this avenue of investigation can never promise certain knowledge about the past, it does present historically informed possibilities to help make sense of what scant

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3D Print after 2300 Years," *Prosthesis* 3 (2021): 190–93; Andreas Otte, "Lessons Learnt from Götz of the Iron Hand," *Prosthesis* 4 (2022): 444–46.

[17] Andreas Otte, "3D Computer-Aided Design Reconstructions and 3D Multi-Material Polymer Replica Printings of the First 'Iron Hand' of Franconian Knight Gottfried (Götz) von Berlichingen (1480–1562): An Overview," *Prosthesis* 2 (2020): 304–12, here 305, 307.

[18] Ibid., 306, 310.

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written and physical evidence remains concerning premodern amputees. It offers a path of exploration in which the journey and the destination are of equal value.

The Kassel Hand

Prosthetic artifacts present a negotiated balance of form and function.[19] Those produced before the twentieth-century medicalization of limb prostheses also point to modes of improvisation in the material world of amputees.[20] Every artifact is, then, highly individualized—by historical and cultural context, and by wearer and maker. The Kassel Hand was a product of a certain cultural and technological moment in early modern Europe. Mechanical hands, which could be made of iron, brass, or wood and include leather straps or textiles such as linen, were custom orders produced in a thriving craft market. With no single craft group dedicated to making them, these prostheses were the creative improvisations of highly skilled master artisans, including locksmiths, clockmakers, armorers, gunsmiths, blacksmiths, and woodworkers.[21]

With some thirty known artifacts, there are more material-culture examples of them than there are textual references. Yet, textual sources have dominated traditional interpretations. The first is a "great man" myth from the history of medicine according to which the surgeon Ambroise Paré invented mechanical limbs in his sixteenth-century treatise on artificial body parts. As the earliest artifact predates this treatise, and the treatise presents the designs of a

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[19] E.g., Jane Draycott, *Prosthetics and Assistive Technology in Ancient Greece and Rome* (Cambridge: Cambridge University Press, 2023), 60, 62.
[20] Beth Linker, *War's Waste: Rehabilitation in World War I America* (Chicago: University of Chicago Press, 2011).
[21] Hausse, *Malleable Body* (n. 1), 155–209.

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Parisian locksmith, that myth has been debunked (though it persists in some scholarship).[22] The second interpretation considers mechanical hands solely as the possessions of wounded knights who used them to hold the reins of their horses and even to wield swords when they returned to battle. Here the threads of a "warrior" myth must be disentangled from the written record. Autobiography and biography, verse chronicle, and occasional archival sources refer to "iron hands" in the context of an injured male combatant losing a hand and acquiring an artificial one. Since the late eighteenth century, this martial association became entwined with the heroicized image of the sixteenth-century knight Götz von Berlichingen.[23] Sources support the notion that riders could use iron hands to hold reins but say nothing about wielding weapons.[24] Significantly, they neither suggest that iron hands' sole function was for battle, nor exclude the possibility that amputees other than knights wore them.

Direct examination of the artifacts complicates traditional interpretations. Most obvious is their form: they are shaped like natural hands with fingernails and skin wrinkles and flesh-toned paint, they are made of expensive materials, and their mechanisms are complex and delicate. This suggests more than an exclusively martial function. Drawing on material evidence, Heidi Hausse, our team's historian, recently expanded scholarly consideration of amputees who may have worn these artifacts to a wider spectrum of men and women from the well-to-do middling and upper classes. These amputee-patrons, she argues, commissioned artificial hands to

[22] For mechanical limbs in Paré: Heidi Hausse, "The Locksmith, the Surgeon, and the Mechanical Hand: Communicating Technical Knowledge in Early Modern Europe," *Technol. Cult.* 60:1 (2019): 34–64; for the myth in recent scholarship: Alanna Skuse, *Surgery and Selfhood in Early Modern England: Altered Bodies and Contexts of Identity* (Cambridge: Cambridge University Press, 2021), 90.
[23] Hausse, *Malleable Body* (n. 1), 162–67.
[24] E.g., Moyse Amirault, *La Vie de François, seigneur de La Noue* . . . (Leiden, 1661), 63.

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send powerful messages about self-sufficiency, status, power, virtue, and intelligence.[25] This posits a performative interpretation of mechanical hands that situates them within fashionable trends among the elite for clever objects that blurred the boundaries of art and nature. It views these objects as tools of agency.

It is easy to critique romanticized claims about mechanical hands, which are legion. From holding a sword in battle to holding a quill to pen a poem, these popular visions fall flat in the face of material culture evidence. It is far more difficult to construct plausible theories about their utility. Our work to create a 3D-printed version of the Kassel Hand began with the idea of building credible theories about its functionality through physical testing.

The Kassel Hand offers a rich foundational case study. This right-hand prosthesis with wrist casing is made of wrought iron. Its hollow shell is riveted together in overlapping sheets. The five fingers flex individually at the metacarpophalangeal joints (the knuckles at the base of the fingers) using toothed wheels and internal pawls and springs. The thumb is only partially operable. There is a release "trigger" at the base of the palm that activates a Y-shaped main lever to free the fingers from a fixed position.[26] Two iron rings at the wrist were likely used to fasten the prosthesis to the wearer, though only one is intact. The artifact's smooth surface is not a solid color, suggesting it was painted, a protective resin is peeling, or the iron is discolored. Engraved fingernails adorn each finger, but no other decorative details are evident. At 626.3 grams (a little over one pound), it is not as heavy as its appearance might suggest. It is dated to the sixteenth

[25] Hausse, *Malleable Body* (n. 1), 199–201.
[26] For diagrams of the mechanisms: Hausse, *Malleable Body* (n. 1), 220, 222.

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century, but the earliest written reference to it is from the late nineteenth. This is an anonymous artifact of unknown provenance, including an unknown wearer and maker.

All of this gives us much to unpack. The Kassel Hand is neither the most elaborate nor the simplest surviving example, suggesting a balance of form and function that makes it a good candidate for examining functionality. Its anonymity requires one to consider a variety of wearers. The Kassel Hand is still mostly operable, providing suggestive evidence of its range of movement and of how one operated it. But it is not fully operable, which means that one still must wrestle with not knowing whether the thumb mechanism ever truly worked the way its design suggests. This helps us acknowledge a crucial qualification to our proposed form of inquiry: we must always consider the possibility that an operable prototype may inadvertently exceed the functionality of the original artifact.

The mechanisms in the Kassel Hand are also appealing. They are largely visible, although at a distorted perspective, through the opening of the wrist. Some artifacts have long forearm casings that obscure their interiors, while others have a solid iron plate fastened over the wrist opening, presumably to protect their mechanisms. Not so with the Kassel Hand. The artifact's mechanical layout also shares striking similarities with the well-known woodcuts from Paré's surgical treatise. This does not suggest a direct connection between the two, but rather shows the woodcuts derived from sixteenth-century artisanal knowledge. That parallel between text and artifact increases opportunities for grounding our exploration with other primary sources. Finally,

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Hausse had previously enlisted the architect Ben Tulman to map the Kassel Hand's interior with photographs and measurements, giving our team a base visual model.[27]

For these reasons, we chose the Kassel Hand. It is not representative of *all* early modern mechanical hands. Rather, we chose it to uncover more about the experiences of its unknown user. While it cannot be known for certain whether this individual was a unilateral or bilateral amputee, we proceeded with the former assumption—an individual with a left hand who at times wore an iron right hand. We set out to learn about that individual through this object he or she possessed, wore, and operated.

The Theoretical Underpinnings

The first component of our proposed method proceeds from a historian's established knowledge base about a prosthetic artifact. A strong one includes well-documented, direct examination of material culture, museum records, consultation with curators and conservators, and relevant primary and secondary sources. Ideally, one has considered the artifact's production process, the wearer's possible social status, and how the wearer may have used the prosthesis. Importantly, this includes historicizing "disability" and notions of impairment in the period one is studying to situate the artifact within that context. All of this together forms the foundation required to begin making historically contextualized ADLs.

[27] Heidi Hausse, "A New View of an Old Prosthesis: Creating a Digital 3D Model of a Sixteenth-Century Iron Hand," in *The Health Humanities in German Studies*, ed. Stephanie M. Hilger (London: Bloomsbury, 2024), 161–72.

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ADLs are a modern notion found in many present-day prosthesis usability and limb functionality assessments.[28] They refer to tasks involved in caring for oneself, including eating and dressing.[29] Within discussions of artificial limbs, ADLs tend to more broadly refer to the everyday activities one wants to perform with a prosthesis.[30] When fitting a device, a prosthetist will consider ADLs in terms of the patient's lifestyle and stated desires or goals. As one prosthetist explained to us, the ADLs of a modern office worker would include typing on a keyboard and touching screens.[31]

Modern usability tests using ADLs translate the movements they encompass into representative activities. These can take an abstracted form, such as the Box and Block Test, which involves moving blocks on a table. They can also take concrete form, as in the University of New Brunswick (UNB) Test, which includes opening a bottle of salad dressing. Both the tests and the ADLs underpinning them were conceived in and apply to life in the modern world, and often to specific cultures.[32] Simply drawing from modern ADLs to consider a premodern prosthesis would result in experiments showing how it might function in the twenty-first century.

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[28] E.g., Virginia Wright, "Prosthetic Outcome Measures for Use with Upper Limb Amputees: A Systematic Review of the Peer-Reviewed Literature, 1970 to 2009," *J. Prosthetics Orthotics* 21, no. 9 (Oct. 2009): 3–63; S. Kestner, "Defining the Relationship between Prosthetic Wrist Function and Its Use in Performing Work Tasks and Activities of Daily Living," *J. Prosthetics Orthotics* 18 (2006): 80–86; B. Kopp et al., "The Arm Motor Ability Test: Reliability, Validity, Sensitivity to Change of an Instrument for Assessing Disabilities in Activities of Daily Living," *Arch. Phys. Med. Rehabil.* 78 (1997): 615–20.

[29] Peter F. Edemekong et al., "Activities of Daily Living," StatPearls (updated June 26, 2023), PMID 29261878, https://www.ncbi.nlm.nih.gov/books/NBK470404/.

[30] E.g., Linda Resnik et al., "Development and Evaluation of the Activities Measure for Upper Limb Amputees," *Arch. Phys. Med. Rehabil.* 94 (2013): 488–94.

[31] Gerald Stark, conversation with author (Zoom), October 19, 2023.

[32] E.g., E. R. Sanderson and R. N. Scott, *UNB Test of Prosthetics Function Manual* (Fredericton: Bioengineering Department, University of New Brunswick, 1985; revised 2012).

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Adapting the concept of ADLs to a specific historical context, however, is a heuristic tool to learn about a prosthesis and its wearer *in the past*.

The goal of creating historically contextualized ADLs is to consider an artifact's functionality, not a wearer's. This distinction is crucial because engineers and clinicians use the performance of ADLs to assess *people* as well as *prostheses*. For example, assessments of limb functionality can examine both an individual's ability to grasp objects after a stroke and the utility of a prosthesis for doing so. Unsurprisingly, assessing people can be problematic. As Katherine Ott argues, the role ADLs play as evaluative metrics in modern health care, tying government benefits of the elderly and those with disabilities to one's "mastery of objects," has roots in nineteenth-century eugenics.[33] By contrast, employing ADLs to assess a prosthesis focuses on the object itself, as a tool, as well as its user experience. While modern assessments consider whether the tool functions as designed, historical inquiry based on ADLs aims to learn more about what it was designed to do. This in turn sheds light on the experiences of its user.

Historically contextualized ADLs offer a powerful way to explore amputees' lived experience. To generate them, the historian must delve into the spaces that prosthesis-wearers inhabited and consider the clothing they wore, the objects they touched, and their day-to-day lives. This challenge demands the historian synthesize what is known of the material world of the period and consider patterns of labor, the role of gender and class, and cultural particularities that influenced everyday experience. Moreover, this must occur in conversation with the artifact, which provides the crucial anchor that keeps the process of broad synthesis focused and

[33] Ott, "Disability Things" (n. 14), 126.

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productive. The guiding question is not what everyday life was like for *anyone*. Rather, it is what everyday life could have looked like for someone who could plausibly have worn *this specific prosthesis*.

The first step is to consider the profile of its possible wearer. To build plausible profiles for the Kassel Hand, Hausse brought all of her knowledge about the artifact to bear. This gave a temporal and geographic scope of sixteenth-century Europe with an emphasis on the German-speaking lands. It also established a range of social-class options from upper-class families living in urban or rural areas: wealthy burghers and patricians, members of the knightly and noble classes, and well-to-do landed families. While the traditional interpretation of iron hands would have restricted consideration to males with military service, she explored the possibilities of a male or female wearer. Uncertainty about the wearer's identity led to an approach focused on social class rather than gender or profession.

After sketching wearer profiles, synthesis begins. In our project, Hausse developed ADLs by beginning with surveys on everyday life in sixteenth-century Europe before shifting to secondary works focused on noble, burgher, and merchant life. This led to consideration of furniture, domestic and institutional interiors, everyday objects, clothing and fashion, dining and drinking, lighting, and horsemanship. She consulted museum catalogs and digital collections of relevant artifacts, museum curators, historians specializing in pertinent subfields such as dress and hippology, and primary sources related to etiquette, horsemanship, and other applicable areas.

The process is dialectical, continually moving between the artifact and the world from which it came. The effect is comparable to Pamela Smith's description of constantly returning to

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a sixteenth-century manuscript while reconstructing the recipes it contained.[34] In Smith's work this involved learning about the back-and-forth movement between textual knowledge and hands-on practices to read the text in new ways. Within the mental exercise of formulating ADLs, this movement is between the material object and the primary and secondary sources that form sounding boards. Each time one introduces the artifact to a new context—sounding out how the prosthesis and its wearer might relate to a set of objects, spaces, activities, or concepts—one's perception changes. This process helps one see a prosthetic artifact differently and consider its wearer more fully.

The exercise is useful as a standalone tool of analysis, as the example of early modern writing demonstrates. This was a path Hausse explored but determined unsuitable for experiment design because the Kassel Hand lacks the dexterity to hold a quill. Creating the ADL, however, led to three findings. The first highlighted the prosthesis's significance as a *right* hand in sixteenth-century European society: the wearer came from the upper classes as reading and writing became increasingly associated with refined manners and high social status, and well-to-do families had growing access to education in urban centers.[35] Writing manuals, which assumed readers would use the right hand, underscore cultural expectations connecting it with proper writing.[36] Second, the ADL focused attention on the wearer's experience. The wearer probably

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[34] Smith, *From Lived Experience* (n. 8), 216–17.

[35] Colette Sirat, *Writing as Handwork: A History of Handwriting in Mediterranean and Western Culture* (Turnhout: Brepols, 2006), 101–7.

[36] E.g., Wolfgang Fugger describes the thumb resting on the left side of the pen because he assumes one is holding it with the right hand: *Ein nutzlich und wolgegrundt Formular, Manncherley schöner schriefften* . . . (Nuremberg, 1553), unpaginated.

wrote with the right hand before undergoing limb loss.[37] The transition afterward could have included learning to write with the left hand, as the Englishman John Stubbs did, or perhaps procuring a prosthesis like the leather or paper hand with an attached writing tool illustrated in surgical treatises.[38] Finally, exploring this ADL highlighted different functions of prosthesis designs. The image of a prosthetic hand holding a pen in the 1585 French edition of Paré's *Les Oeuvres* clearly imitates the instructional woodcuts of writing manuals demonstrating correct postures (Figures 3–4).[39] It has a single position that parallels "proper writing" illustrations, implying a promise of "normalcy" through a prosthetic writing tool. These sounding boards prompted Hausse to reframe her view of the Kassel Hand as "lacking" the dexterity to grasp a quill. More accurately, the artifact is *designed* to do something else.

[37] W. C. Watt, "Appendix C. Why Handwriting Is Right-Handed (Except When It Isn't)," in Sirat, *Writing as Handwork* (n. 35), 515–17.
[38] Christopher Burlinson, "John Stubbs' Left-Handed Letters," in *Cultures of Correspondence in Early Modern Britain*, ed. James Daybell and Andrew Gordon (Philadelphia: University of Pennsylvania Press, 2016), 156–68; Ambroise Paré, *Les Oeuvres* (Paris, 1585), 917.
[39] Paré, *Les Oeuvres* (n. 38), 917.

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Figure 3. Wolfgang Fugger, *Ein nutzlich und wolgegrundt Formular, Manncherley schöner schriefften* . . . (Nuremberg, 1553). Source: gallica.bnf.fr / Bibliothèque nationale de France.

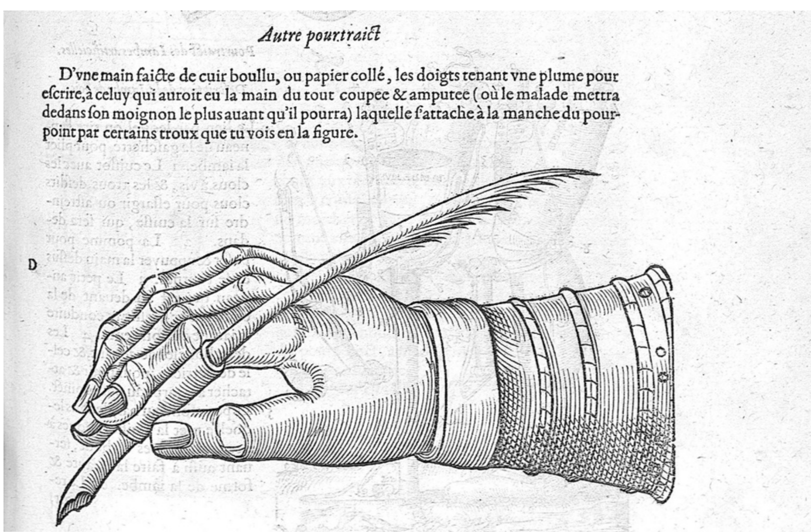

Figure 4. Ambroise Paré, *Les Oeuvres* . . . (Paris, 1585), 917. Source: BIU Santé (Paris).

The historian must choose which ADLs warrant testing and develop thorough data profiles of them. Setting a maximum number that one has the resources to test provides scope. In

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our case, Hausse focused on five ADLs. The number was small enough for a study participant to attempt in one session, but large enough to cover a variety of grasps and motions. Our ADLs were relevant to what an upper-class wearer of different genders and occupations might do. Moreover, they together allowed exploration of three interpretations of the artifact:

1. Performative: our contention that mechanical hands were all to some extent intended to impress others.
2. Traditional: the view of mechanical hands as the possessions of wounded knights used to hold the reins of their horses.
3. Mundane: the possibility mechanical hands were useful for prosaic, everyday activities.

The diagram in Figure 5 shows the relationship between these interpretations and the following ADLs: using horse reins, holding drinking vessels, opening chest lids, carrying everyday objects, and untying and tying a lace.

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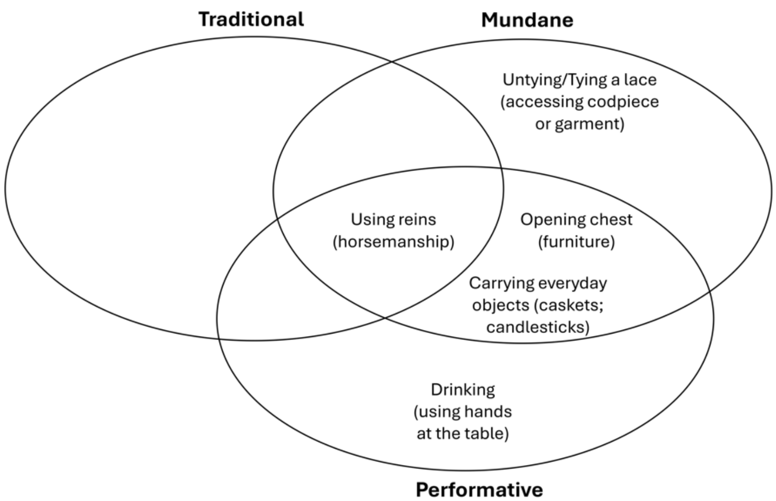

Figure 5. Diagram of early modern ADLs for the Kassel Hand. Source: Heidi Hausse.

Contrasting two of these ADLs—holding drinking vessels and opening chest lids—illustrates how different activities can focus on different questions. Holding drinking vessels is a performative activity, while opening chest lids mixes performative with mundane. These explore two spheres of life. The former places the wearer dining at the table with others. Drinking vessels present the most viable objects to test in this setting because the Kassel Hand was not designed with the dexterity to hold unmodified utensils.[40] As early modern etiquette books instruct, good table manners dictated using the *right* hand to use a knife or cup.[41] Indeed, Desiderius Erasmus

[40] On cutlery and cups: Raffaella Sarti, *Europe at Home: Family and Material Culture, 1500–1800* (New Haven, Conn.: Yale University Press, 2002), 152–53; Ken Albala, *Food in Early Modern Europe* (Westport, Conn.: Greenwood, 2003), 103–5; Bernd Roeck, *Civic Culture and Everyday Life in Early Modern Germany* (Leiden: Brill, 2006), 64.
[41] E.g., Desiderius Erasmus, *A Handbook on Good Manners for Children: De Civilitate Morum Puerilium Libellus*, trans. Eleanor Merchant (London: Preface, 2008), 44.

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warned young boys to "make sure you don't use your left hand" to reach for or pour something.[42] Furthermore, one should "always keep both hands on the table. . . . It's impolite to keep one or both hands on your lap."[43] Testing drinking vessels could suggest whether it was feasible to use the Kassel Hand to follow social etiquette for this task. If testing proves this unfeasible, that could instead suggest the utility of the prosthesis's form—its natural shape and engraved fingernails—for politely displaying both hands above the table.

Opening a chest directs attention to more mundane tasks. Chests were the dominant type of organizational furniture in middle- and upper-class sixteenth-century homes. They could contain many disparate kinds of objects thrown together—from linen to cheese—and offer decoration and additional seating.[44] While holding drinking vessels highlights the role of etiquette in influencing body movement, lifting chest lids underscores the physical environment. The size and heft of chests usually made opening them a two-handed task. Once opened, their lids were difficult to hold for long stretches. Depending on how a chest was positioned in a room, one could lean its lid against a wall or other vertical surface. Otherwise, chests often had smaller compartments or side drawers inside with their own removable tops that one could position at the inner corner to keep a lid propped open.[45] Testing this ADL presses the question of whether the Kassel Hand was a tool for everyday use or special occasions.

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[42] Ibid., 64.
[43] Ibid., 42–43.
[44] Sarti, *Europe at Home* (n. 40), 128; Roeck, *Civic Culture* (n. 40), 42, 45.
[45] Thorsten Albrecht, *Truhen, Kisten, Laden: vom Mittelalter bis zur Gegenwart: am Beispiel der Lüneburger Heide* (Petersberg: Michael Imhof, 1997), 48.

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These two ADLs also concentrate on different aspects of the artifact's design and capabilities. For drinking vessels, the level of articulation in a mechanical hand's fingers is essential. Whether one can move the four fingers individually or in pairs (index-and-middle-fingers and ring-and-little-fingers) or as a single block (all four at once) affects the minimum grasping surface a prosthesis requires to hold an object, as well as the minimum space needed to insert fingers into handles.[46] For example, a tankard with a handle too small to accommodate more than two fingers of a museum collection assistant's hand is a nonstarter for a prosthesis with four fingers in a single block. As the Kassel Hand's fingers move individually, and therefore could grasp narrower and irregular surfaces and fit in smaller spaces than less-articulated prostheses, a variety of vessels appeared viable for testing different grasps. Working with the Fitzwilliam Museum (University of Cambridge) and the Hentrich Glass Museum (Museum Kunstpalast Foundation, Düsseldorf), Hausse gathered data for seven drinking vessels—tankards, wine glasses, Römer and Berkemeyer cups. These offer a range of grasping surface sizes and shapes with which to test the impact of the Kassel Hand's level of finger articulation on its functionality while dining.

Lifting chest lids, by contrast, examines the prosthesis's ability to withstand force in tasks requiring strength. In addition, this is commonly a two-handed activity. Given the many styles of lids, with some extending significantly past the body of the chest and others nearly flush with it,[47] this activity could involve various grasps that distribute the weight of the lid differently. For

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[46] For prosthetic finger movement with artifact examples: Hausse, *Malleable Body* (n. 1), 194.
[47] Edla Colsman, *Möbel: Gotik bis Jugendstil: die Sammlung im Museum für Angewandte Kunst Köln* (Stuttgart: Arnold, 1999); Albrecht, *Truhen* (n. 45); Gerdi Maierbacher-Legl, *Truhe und Schrank: graphisch dekorierte Möbel der süddeutschen Spätrenaissance* (Munich: Deutscher Kunstverlag, 1997).

example, using the tips of the fingers versus the lateral sides of the fingers affects the loading of a hand's joints. Christian Schreiber, a restorer at Landesmuseum Württemberg (Stuttgart), provided detailed hand-drawn diagrams of two sixteenth-century chests from their collection, which provided measurements of the lids' dimensions and the spaces available for gripping them. To determine the weight of the chest lids, Schreiber used a pull scale designed to measure the weight of luggage. At 8 and 12 kilograms, or roughly 17.5 and 26.5 pounds, the force required to lift these lids was significant for just the fingertips—natural or prosthetic—to bear. Whether the prosthesis can withstand the concentration of that much force on the fingertips could suggest its functionality at this task, prompt experimenting with modified grasps, or even eliminate this ADL from further consideration.

The theoretical component of the method takes an artifact through a whirlwind of hypothetical scenarios that present themselves only when one steps outside of one's direct area of expertise. Developing ADLs for the Kassel Hand, for example, made Hausse deeply conscious of the significance of right or left hand use, as well as two-handed use, in everyday activities in early modern Europe. It brought to the fore the different kinds of practical situations and social and cultural pressures the wearer of a particular prosthesis might have encountered. The process also highlighted the various kinds of physicality required for everyday activities—whether the dexterous lacing of garments or the lifting of a weighty lid—and sparked questions about how these affected an amputee's experience.

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The Material Element

The second component of our method takes place while formulating ADLs: the creation of a 3D-printed model of the artifact. Doing so not only builds on museum scholars and archaeologists' work with 3D-printing technology, but also is compatible with trends in modern prosthesis design and manufacturing.[48] 3D printing of prosthetic limbs has advanced dramatically since the first 3D-printed hands appeared less than two decades ago. Today amputees can acquire 3D-printed hands, arms, and feet, which their advocates tout as more affordable than other options.

These developments in modern prosthetics are important to our work here for two reasons. First, they provide historians with resources on using 3D printing in ways that create safe user interactions. The second concerns collaboration. Rather than learning how to use CAD software and purchasing a 3D printer to become an island of productivity, a historian can reach out to others with technical design skills, experience with modern prostheses, and access to equipment. 3D printing forms a common point of interest with prosthetists, artificial limb companies, and medical researchers. Our collaboration at Auburn began when Hausse contacted Chad Rose, our team's mechanical engineer, because of his involvement in creating wearable technologies using 3D printing. The creation of our Kassel Hand prototype took place in Rose's Wearable and Bio-Robotics (WeBR) Lab at the university. Awareness of trends in modern

[48] E.g., David Seibt, *Socio-material Construction of Users: 3D Printing and the Digitalization of the Prosthetics Industry* (Abingdon: Routledge, 2023).

prosthetics design and manufacture can aid scholars in determining to whom they might reach out to begin a dialogue.

Before initiating contact, historians should be prepared to clearly communicate their motivations for creating a printable 3D model. *What is the prototype supposed to do?* Perhaps it is supposed to reproduce the appearance of a prosthetic artifact. Or perhaps it needs to move in the same way as one or wear out over time in a similar fashion. How a model looks, works, and wears are different things. Because a printable 3D model will not be a replica, one must decide which aspects of the artifact are requirements and which can be bent as needed to meet those requirements. Identifying these at the outset guides discussions about acceptable variability between model and artifact.

For example, we agreed the most important aspect of the Kassel Hand that we wanted to model was its internal mechanisms. This influenced decisions throughout the design process, including how we compensated for differences in material properties—strength and flexibility—of the artifact's iron hand and our plastic one. We could have switched to expensive metal parts, as the Offenburg researchers suggested when facing similar challenges.[49] Instead, we decided to increase the thickness of the hand's plastic shell by one millimeter. This kept materials inexpensive—a priority for making our design open access—but meant the model's dimensions would need to change in one of two ways. Either its exterior could remain the same and the space within shrink slightly, or its interior could remain the same and its exterior dimensions grow slightly. Because of our requirement concerning the mechanisms, we decided to preserve

[49] Otte, "Lessons Learnt" (n. 16), 446.

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the interior space. To design a model with intention, the requirements must be clear from the outset and adhered to consistently.

The next step is to work with the collaborator to consider resources. Designing and making a 3D-printed model is an iterative process that involves printing, identifying problems, revising, and reprinting. Inexpensive materials are essential for making this feasible. Fortunately, the most commonly used polymer (plastic) filament for 3D printing, PLA, is usually less than thirty dollars per kilo (we used it exclusively for the Kassel Hand model). Capable polymer printers, such as the Prusa MK4, can be obtained for under a thousand dollars. For tighter budgets, a decent polymer printer like the Creality Ender 3 can be had for a couple of hundred dollars. There are also services to whom one can send files for printing. In our case, Rose had access to significant printing resources through Auburn's ME3D Lab, including the Dremel 3D45 and Anycubic Kobra 2 Max used to print the Kassel Hand prototype. The printing capabilities available can inform the collaborator's choice of manufacturing techniques. For example, our model has a hand shell assembled in two pieces rather than several because we had access to the large print-volume Kobra 2 Max.

Next, the work of making the CAD model begins. We used SolidWorks, but there are other software options, including AutoCAD, Creo, and Rhino3D. One can generate 3D part models in two main ways, automated means or manually. Automated means refers to 3D scanning technologies (LiDAR, laser scanning, etc.) or software packages that create point

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clouds from 2D images that can be turned into models.[50] Manual modeling, by contrast, involves designing from photographs, measurements, or drawings (also called drafting).[51] Rose and three of his students created our printable 3D model through a combination of photographs and drawings, as well as Tulman's aforementioned digital model.

The historian should be cognizant of the nuanced decision-making required to develop models of manmade objects. Inherent in the designer's work is turning approximations of any real-world shapes into a 3D model. The limitations of using 2D images of 3D objects include distortion, occlusions, and perspective that require some measurements to be adjusted or extrapolated.[52] Additionally, even using 3D scans of objects' exteriors requires judicious speculation—most premodern artifacts are corroded and fragmentary, rather than whole, and artifacts can also have hollow *interiors* to reckon with. Similar to archaeologists reconstructing incomplete finds, historians and their collaborators must make and carefully record "educated suppositions" about damaged, missing, or visually obscured parts when creating a three-dimensional representation of the whole.[53] Historians must ensure decisions comport with historical knowledge and the archaeological record. For example, when Rose and his students changed the shape of a spring in our model's thumb mechanism from a curved flat spring to a leaf spring with a bend in the middle, this adjusted a part only partially visible in the artifact

[50] Several companies, e.g., Faro and Creaform, specialize in 3D scanning technologies. Converting 2D static or video images into point clouds has been a vibrant research topic for several decades, with algorithms available commercially, e.g., Polycam 3D Scanner application on iPhone.
[51] E.g., Frederick E. Giesecke et al., *Technical Drawing* (Upper Saddle River, N.J.: Prentice Hall, 2009).
[52] E.g., Otte, "3D Computer-Aided Design" (n. 17), 305.
[53] Bischoff et al., "Ship-Find" (n. 5), 239.

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(Figure 6).[54] This solution matched what could be seen (the thumb's spring indeed has a bend) and was supported by other primary source evidence (leaf springs appear in other early modern mechanical hands).[55]

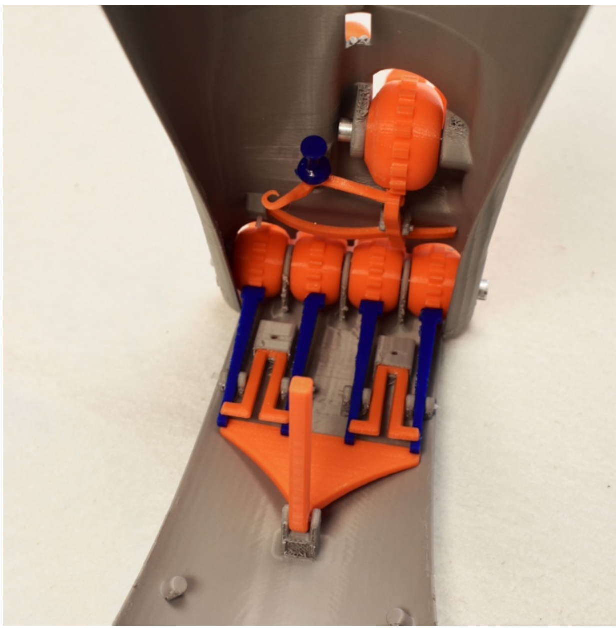

Figure 6. Interior of Kassel Hand Prototype 2.5, April 2024. Leaf-spring with bend in middle appears below thumb lever with curlicue end. The four blue pawls that lock into finger ratchets experienced slippage under pressure. Source: Heidi Hausse.

Moving from design to assembly—building the physical model from printed parts—is an iterative process that takes time. The actual printing and manufacturing can deviate from plans based on printer and material quality or the skill and experience of the assembler. More significantly, this is iterative because printing tests ideas for designs of a complete

[54] "Engineering History" Team Meeting (Auburn, Ala.), January 30, 2024.

[55] E.g., Christian von Mechel, *Die eiserne Hand des tapfern deutschen Ritters Götz von Berlichingen* (Berlin: Decker, 1815), Tab. II.

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(nonfragmentary) and operational version of an artifact that is likely neither. Each printing allows a team to critique and assess.

The pawls of the Kassel Hand model illustrate the importance of this iterative process. Each finger has a toothed wheel, or ratchet, at its base. There is a pawl for each designed to catch in the grooves of the wheel to fix a finger in a locked position (Figure 6). Several iterations were required to develop working pawls. In the first printing, they were too short to reach the ratchets.[56] Over time, we lengthened them to match the artifact and thickened them to imitate the functional strength of its metal springs. Eventually the fingers moved like the artifact's, locking in increments when pressed in the direction of the palm. But if we applied pressure in the opposite direction, the pawls slipped backward between the rachets' teeth instead of keeping the fingers fixed. In effect, we could move and pose the model like the artifact, but we could not *use* it. Finally, more refining of the rachets' teeth enabled the pawls to hold firmly.[57] The pawls trace the model's development from a design that modeled the artifact not just visually, but operationally. Moreover, the slippage problem marked the moment that what we could explore with the model moved past what could be done without risking damage to the artifact: we (unsuccessfully) attempted to lift five, seven, and fifteen pounds.

The process of creating a 3D-printed model leads to suggestive insights about the artifact, its making, and its wearer's experience. The Kassel Hand's thumb lever, which connects the thumb to the hand's main release lever, demonstrates this. Activating the main lever causes the

[56] Avinash Baskaran, email to authors, August 18, 2022.
[57] Peden Jones, email to authors, May 20, 2024.

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thumb lever to lift the thumb's pawl and release its ratchet.[58] One end of the thumb lever, which touches the interior surface of the prosthesis, curls into a "curlicue" shape (Figure 6). Why a curlicue? It does not appear to have a function in operating the mechanisms. However, our team members hypothesized that it could have allowed flexibility for installing the mechanism when the prosthesis was made and been useful for its maintenance. As Rose suggested, assuming the Kassel Hand's interior components were made to fit inside of its hollow shell, it would have been much easier for a locksmith to twist extra material at the end of the thumb's lever into a curl rather than judge the perfect length of a flat-end piece. Moreover, Peden Jones, a graduate student worker, proposed it could have served as a "tuning piece."[59] He developed the idea while curling and uncurling a magnet wire he inserted into the prototype to physically determine the thumb lever's dimensions. As Jones explained, the artifact's thumb lever was a difficult piece that would have required many fine adjustments: if it were too long, the thumb would never lock; if it were too short, the thumb could not be unlocked. An artisan could curl or uncurl the thumb lever's end with pliers to create the right action in the mechanisms. Wearable technology often requires adjustment over time, and Jones encouraged us to think of the curlicue as facilitating the Kassel Hand's long-term upkeep.

Collaborative work produces a meaningful 3D-printed model of a historical prosthesis. The iterative process involved in its creation constantly returns the historian to the artifact to set parameters, answer questions, and reconsider it from others' perspectives. Creating an operable 3D-printed prosthesis brings what Pamela H. Smith refers to as a "heightened" attention to the

[58] Hausse, *Malleable Body* (n. 1), 222 (diagram).
[59] Peden Jones, entry in "Engineering History" work log, May 17, 2024.

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details of an object and its making.[60] Articulating what a prototype captures and what it misses, how it is similar and how it differs from the artifact, attunes the historian to the *experience* of the artifact in a new way. The result is not simply a physical model, but also fruitful insight into the artifact. Using inexpensive materials not only makes the iterative process feasible, but also creates a shareable—and strikingly tangible—form of historical knowledge in printable files. We encourage scholars who explore making such models to conceive of this work as both furthering research within their field *and* expanding access to the world of premodern amputees in an interactive way.

The Communal Component

Humanistic study of a historical prosthesis through experiments calls for the historian to engage in collaborative conversations with others outside of the project. A third component of our method, then, is to hold discussions with external interlocutors. These should be individuals concerned about advocating for those with disabilities and invested in discussing inclusivity from a critical perspective. While this component can take many forms, its goals are to decenter one's narrow academic questions and expertise when approaching experiment design, consider ways to incorporate amputees' perspectives, and build relationships with one's community to situate the study beneficially within it. This communal component approaches whether to include amputees as participants, and discusses how to involve them in the project, as open-ended questions rather than foregone conclusions. Discussing these issues with individuals outside of the project

[60] Smith, *From Lived Experience* (n. 8), 206.

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ensures the priorities and interpretations of one's own subfield are but one perspective guiding decision-making. This component is not a substitute for working with the internal review board (IRB) of one's institution; rather, incorporating this component should influence the protocols one submits to IRB for approval.

Experimenting with models of historical prostheses entails a special obligation to invite members of the present-day disability community into the process of recovering the past of premodern amputees. There are two reasons for this. First, present-day amputees are stakeholders in that project. Inviting advocates' input in experiment design helps a historian consider how to include those stakeholders from the conception of experiments to the presentation of data. It contributes to disability history's fundamental desire to create a useable past by challenging modern assumptions and locating historical agency.[61] A useful model comes from collaborative ethnography, which seeks to include the people who form the focus of a study in shaping a final research product.[62] Within ethnography, the approach transforms "informants" into "co-intellectuals" through "collaborative conversations" and disrupts the power dynamic that privileges the academic lens.[63] Similarly, historians experimenting with historical prostheses should cede some autonomy in project design and public messaging to the suggestions of responsible external interlocutors to create a humanities-guided form of experimental inquiry.

[61] E.g., Catherine Kudlick, "Comment: On the Borderland of Medical and Disability History," *Bull. Hist. Med.* 87, no. 4 (2013): 551.
[62] Luke Eric Lassiter, *The Chicago Guide to Collaborative Ethnography* (Chicago: University of Chicago Press, 2005), 8–9.
[63] Ibid., 8

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A second reason for this obligation is that present-day amputees have much-needed insight into lived experience that enriches a historical project. This is not to suggest that human experience is universal or unchanging through time. Twentieth-century studies of phantom limb phenomenon, for example, reveal that amputees' descriptions varied by decade.[64] Nevertheless, while the use and perception of limb prostheses are historically and culturally contingent, those with experience using one have a crucial vantage point from which to ask questions, make comparisons, and test usability. The historian can work with individual amputees to productively apply that insight without simply projecting modern experience backward onto an artifact. Drawing on collaborative ethnography's concept of "co-intellectuals" is again useful. While present-day amputees are not the subject of a study about a historical prosthesis, their insights into modern prosthesis use make them invaluable co-intellectuals.

When conceptualizing the format of these conversations, there are two scheduling elements to consider. Dialogue should allow for input *before* experiment design begins and for follow-up feedback after designs are made. The process of establishing interlocutors and holding initial discussions should therefore take place while formulating ADLs. Time should also be built into the project workflow to revise designs based on feedback. One could meet with interlocutors in a group or individually, over several sessions or in two or three in-depth sessions timed at key stages. In our project, Hausse held two formal conversations with each external interlocutor—one before and one after experiment design. We did not finalize our experiment protocol until receiving positive feedback.

[64] Cassandra Crawford, *Phantom Limb: Amputation, Embodiment, and Prosthetic Technology* (New York: New York University Press, 2014), 212.

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Locating interlocutors is not unlike the preliminary stage of an oral history project.[65] One must identify who might be relevant to contact, reach out by phone and email, hold informal conversations, develop a network of contacts by following up on leads, and thereby establish who might be best suited for formal discussions. In our case, Hausse reached out to a combination of organizations and individuals numbering just under twenty. She began with contacts at her university, then identified resources for disability support and advocacy in her region as well as national organizations.

The number and makeup of interlocutors will vary based on one's project, but ideally they together provide a range of perspectives. We worked with four individuals who each came to the discussions from a different and valuable point of view: a local disability advocate and ambassador for Friedrich's Ataxia with ties to our university community, a regional disability advocate who is an above-the-knee amputee and an ambassador for an osseointegration company, an influential prosthetist and director of clinical affairs at a major prosthetics company, and a historian engaged with disability studies at another university. Together, the four interlocutors created a balanced dialogue about experiment design and our presentation of the Kassel Hand model to the public.

Collaborative conversations before experiment design can productively consider whether to seek out participants with limb loss, without limb loss, or both. Our interlocutors unanimously agreed we *should* include at least one amputee. Gini Thomas, the regional advocate, pointed to

[65] Valerie Yow, *Recording Oral History: A Guide for the Humanities and Social Sciences* (Lanham, Md.: Rowman & Littlefield, 2015), 77–78.

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the physical experience of being an amputee as essential to understanding prosthesis use.[66] Comparing the responses of someone without limb loss to an amputee's would, she suggested, provide striking differences that we as investigators should want to know and explore. Likewise, Dr. Gerald Stark, the prosthetist, suggested that amputees would teach us a great deal about using prostheses that we could not discover ourselves.[67] Through Thomas and Stark's discussions, the notion of including amputees as co-intellectuals in the experimental enterprise took firmer shape.

These discussions are also important opportunities to reframe the forms that participation in a study might take. For example, we initially took for granted that participation meant wearing the 3D-printed model to perform tasks. But three interlocutors recommended we present wearing the model to participants as an option rather than as an expectation. This would prioritize participants' agency. Noah Griffith, the local advocate, put this most succinctly by inquiring why a prosthesis-user must put on the model to offer insight about it.[68] If we were planning to learn about the model by watching others perform tasks with it, would it not stand to reason that an upper-limb amputee might develop critical thoughts worth sharing based on observing the model in action as well? Turning the form of participation into a choice also expanded opportunities to involve amputees. The Kassel Hand is a right-hand prosthesis with a wrist casing designed for a residual limb—a forearm—of a certain length. The option to observe opened participation to upper-limb amputees with a greater variety of residual limbs. Building on this idea were suggestions about offering participants the choice to include their thoughts and words with our

[66] Gini Thomas, conversation with author (Auburn, Ala.), November 28, 2023.
[67] Gerald Stark, conversation with author (Zoom), October 9, 2023.
[68] Noah Griffith, conversation with author (Auburn, Ala.), October 19, 2023.

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open access files of the Kassel Hand model. Jacob Baum, the external scholar, pointed to the role the digital humanities could play in positively incorporating the viewpoints of amputees into the public-facing aspects of our work.[69] These discussions helped us reenvision participation in an inclusive way.

Finally, collaborative conversations are crucial for pointing out aspects of prosthesis testing that are obvious to those experienced with their use, but of which a historian may be entirely ignorant. The involvement of prosthetists in our project demonstrates this vividly. Two interlocutors strongly felt that we needed to involve a prosthetist in fitting the model to an amputee participant and have one present during experimental tasks. They explained this would ensure the comfort and support of an amputee, and in doing so was a significant way to counter the power imbalance of an experiment session. They also emphasized that we should have a prosthetist on-site to address any unexpected issues with socket fitting. Thomas reached out to a contact at the Opelika clinic of Alabama Artificial Limb & Orthopedic Service Inc., who directed Matthew Jones, a prosthetic/orthotic resident, to generously offer his assistance on the project. Jones, who had a particular interest in 3D printing for prosthetics and orthotics, agreed to help advise on socket fitment, locate participants, and coordinate holding experiments in the local clinic. This proved to be a fruitful intellectual development; it also created an important point of support for possible participants and underscored the wider network of amputees and prosthetists that Thomas had suggested would be interested in the project.

[69] Jacob Baum, conversation with author (Zoom), November 14, 2023.

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There are several benefits from engaging with external interlocutors well before beginning to design experiments for a 3D-printed model. From developing a broad view of the resources available for people with disabilities in one's local and regional communities to establishing individual relationships that can provide sustained feedback from a nonacademic perspective, the process begins creating ties between the project and potential stakeholders in one's community. The conversations themselves can challenge assumptions about human subject research protocols, work through tough moral and intellectual questions, and help situate a project so that it is productive and beneficial for more than just one's subfield of research.

The Integrative Stage

The fourth component of our method brings together the work of the first three. Historically contextualized ADLs and the first round of discussions with external interlocutors must be completed first. Creating the physical 3D model can be in progress, though ideally one has printed at least two versions of the prototype and is far into the process of refining it. Working with intention from start to finish means that each stage of the work contributes essential intellectual and, in the case of the prototype, physical material required to design meaningful experimental assessments.

The limitations inherent in this undertaking are manifold. On the one side, there is uncertainty about the precise body movements involved in performing activities in the premodern past. For example, dress historians do not know the exact motions a sixteenth-century

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person used to tie a lace into a bow.[70] On the other side, there is uncertainty about how an individual amputee may have modified those movements—turning a two-handed activity into a one-handed activity, using improvised tools, or switching which hand performed dexterous tasks. Experimental assessments of a historical prosthesis are a speculative exercise. Despite these challenges, the process of experiment design can offer unexpected insights well worth the caution with which we must treat them.

Our experiment design was a collaborative effort. If one's collaborator for the 3D model has a background in wearable technology, continuing that collaboration into experiment design has the advantage of familiarity with the prototype and the artifact. One could also consult with a prosthetist or, if one's university has a physical therapy program, reach out to the faculty involved. Otherwise, one could draw from the plans we developed as appropriate.

The first step is to establish guiding parameters about participants. In our project, we referred to a summary of points from our external interlocutor discussions during this deliberation. We decided to recruit between one and three amputee participants. In addition, we agreed participants would choose whether to physically manipulate the model or observe a team member do so. All participants would then talk about the experience in an open-ended interview. This synthesized Rose and Hausse's disciplinary sensibilities as engineer and historian and steered our approach to create experiments that would treat participants as co-intellectuals.

The next consideration concerns scope: choosing the number of ADLs to test. This is a matter of one's resources and intellectual goals. One could hone in on a small subset of ADLs—

[70] Sarah Bendall, conversation with author (Zoom), October 16, 2023.

as few as one or two—in an exhaustive investigation or undertake a pilot investigation into a range of ADLs. The former concentrates time and resources to explore one task through several repetitions and multiple versions of a test, while the latter spreads time and resources across several tasks to explore them all in a preliminary fashion with few repetitions or versions. Both paths have value.

In our project, we discussed options while going over the five ADL data profiles and a synthesis file that compiled numerical data of early modern objects from all ADL profiles (i.e., drinking vessels, bridle reins, candlesticks, caskets, laces, and chest lids). The latter provided ranges of representative measurements, weights, materials, shapes, and qualitative notes about holding and lifting objects from conservators and curators. Though we discussed narrowing our focus to a single ADL, we agreed more activities would allow us to consider the original artifact through all three interpretive lenses: traditional, performative, and mundane. Our results would then indicate which activities warrant further testing and which to eliminate from consideration.

Once the number of ADLs to test is decided, one can begin translating them into abstract tasks. Conceiving of experiment activities as abstract tasks rather than literal simulations focuses attention on patterns of positions and movements. Intellectually, this is useful for considering a historical actor's lived experience. Practically, a pattern in ADLs allows for one abstract task to test multiple ADLs and reduces the amount of time a participant wears the model. Whether an artifact is an upper- or lower-limb prothesis will affect the modern usability assessments one might draw on for inspiration. As the Kassel Hand is an upper limb, we explored accordingly.[71]

[71] E.g., Resnik et al., "Development and Evaluation" (n. 30); C. M. Light, P. H. Chappell, and P. J. Kyberd, "Quantifying Impaired Hand Function in the Clinical Environment," in *MEC '99: MyoElectric*

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In our project, modern taxonomies of hand positions offered a useful language to talk about different kinds of hand grasps and consider the movement, strength, and dexterity involved.[72] "The GRASP Taxonomy," for example, synthesizes hand-grasp classifications into an overarching scheme organized by "power," "intermediate," and "precision" grips.[73] In a power grip, the hand keeps an object in a rigid hold, and movement of the arm is required to move the object. A precision grip, by contrast, allows a hand to perform movements on an object without any arm movement required, such as writing with a pencil. An intermediate grip involves a combination of power and precision. Furthermore, the GRASP Taxonomy gives attention to the position of the thumb and whether the grip applies force to the palm, finger pads, or sides of the fingers.[74] As modern grasp taxonomies like this one derive from studies of humans using their hands in the modern world, it is important to draw only what is useful for conceptualizing body movement in the past, rather than adopt any one of them wholesale.[75]

Controls/Powered Prosthetics Symposium Conference Proceedings (University of New Brunswick, August 1999), 43–48; Sukhvinder Kalsi-Ryan et al., "The Graded Redefined Assessment of Strength Sensibility and Prehension: Reliability and Validity," *J. Neurotrauma* 29, no. 5 (2012): 905–14; Michelle McDonnell, "Action Research Arm Test," *Austral. J. Physiotherapy* 54, no. 3 (2008): 220; Barbara Singer and Jimena Garcia-Vega, "The Fugl-Meyer Upper Extremity Scale," *J. Physiotherapy* 63, no. 1 (2017): 53.

[72] E.g., Thomas Feix et al., "The GRASP Taxonomy of Human Grasp Types," *IEEE Trans. Human-Machine Syst.* 46, no. 1 (2015): 66–77; Mark R. Cutkosky, "On Grasp Choice, Grasp Models, and the Design of Hands for Manufacturing Tasks," *IEEE Trans. Robotics Automation* 5, no. 3 (1989): 269–79; Light et al., "Quantifying Impaired Hand Function" (n. 71); Peter J. Kyberd et al., "Case Studies to Demonstrate the Range of Applications of the Southampton Hand Assessment Procedure," *Brit. J. Occup. Therapy* 75, no. 5 (2009): 212–18; Kalsi-Ryan et al., "Graded Redefined Assessment" (n. 71).

[73] Feix et al., "GRASP Taxonomy" (n. 72), 70.

[74] Ibid.

[75] E.g., Joshua Z. Zheng, Sara De La Rosa, and Aaron M. Dollar, "An Investigation of Grasp Type and Frequency in Daily Household and Machine Shop Tasks," *IEEE Int. Conference Robotics Automation* (2011): 4169–75.

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We used the idea of patterns in hand positions to discuss grasps for the objects in our ADL data profiles, drawing on primary source evidence related to hand movement where possible. This included consideration of both the shape of a grasp and the nature of the grip. For example, a cylindrical grasp, with the thumb held in opposition to the fingers to create a "C" or "O" shape, appeared reasonable for multiple objects. This included a late sixteenth-century Römer glass, a goblet with a hemisphere-like cup set on a cylinder trunk, from the Hentrich Glass Museum, and an early seventeenth-century bell-metal candlestick with a wide drip pan set on a trumpet-shaped base at the Victoria and Albert Museum.[76] A cylindrical grasp, however, would take different forms depending on whether one used a natural or prosthetic hand. A natural hand might hold both the goblet and the candlestick in a rigid position (a "power grip" in GRASP Taxonomy), which would exert force to lift the items while also keeping them stable. This power grip would be difficult for someone wearing a passively operated iron prosthesis because of the precise calculation of pressure needed to lift with just the right amount of force—positioning the metal fingers so they are neither too loose to drop nor too tight to crush. Rose proposed that the Kassel Hand appears well-suited for a slightly different version of a cylindrical grasp. Its wearer could have positioned the fingers just below where each object widened—the maximum width of the goblet's cup and the drip pan of the candlestick. This could stabilize the objects while lifting them from *below* rather than from their sides. Working through positions and grasps transitions focus from an ADL more generally to an activity as it may have been experienced specifically by a historical prosthesis's wearer.

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[76] Römer (Nr. LP 2010-113), https://www.duesseldorf.de/dkult/DE-MUS-038015/326827; Candlestick (Nr. M.2-1956), https://collections.vam.ac.uk/item/O93012/candlestick-unknown/.

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Once one identifies hand positions and movements, it is time to configure experimental activities. We recommend drawing ideas from modern usability assessments. For example, we found inspiration in the Southampton Hand Assessment Procedure (SHAP), which uses timed measurements to evaluate functionality of natural and prosthetic hands. It employs a combination of abstract tasks, such as moving geometric objects, and ADLs, including picking up coins.[77] We created abstract tasks with a mixture of 3D-printed shapes and purchased materials that would reflect representative dimensions of early modern objects in the ADL data profiles. For example, we developed three 3D-printed cups that incorporate key dimensions of five drinking vessels and a candlestick that allow different grasp apertures for a cylindrical grasp (Figure 7).

Figure 7. 3D-printed objects for experimental tasks, December 2024. Source: Heidi Hausse.

Another major element to consider is how to collect experimental data. Modern functionality assessments focus on quantitative data, including coarse measures, ranging from

[77] Light et al., "Quantifying Impaired Hand Function" (n. 71), 43–44.

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binary (one can complete a task in any amount of time), to timed (how many tasks can be completed in a certain amount of time), to more granular measures (e.g., how much effort is required to perform tasks). Furthermore, many assessments of prostheses include a questionnaire modeled on the System Usability Scale, using participants' answers to establish a prosthesis's perceived usability.[78]

Our project combined aspects of modern assessments with oral history techniques and the dialogic approach of collaborative ethnography to allow for quantitative and qualitative data. We drew from examples such as SHAP to prioritize time measurement to gather quantitative data while a participant performed experimental tasks during a twenty-minute period. Rather than giving questionnaires following the tasks, we opted for Hausse to conduct an hour-long interview. This offered a qualitative method that would allow us, as Valerie Raleigh Yow says of oral history interviews, to gain "information not imagined at the beginning."[79] Interviews are open-ended: this format would allow a participant to shift the focus into unexpected directions, determine which words best describe their experience with the model, and make comparisons to modern prostheses at will. Rather than recording the participant's life history, the interview would focus on the participant's experience with prostheses and the 3D-printed model. The approach would bring amputees' perspectives into the project while keeping the Kassel Hand's unknown wearer the subject of study. This carried through our intention to incorporate amputee

[78] E.g., James R. Lewis, "The System Usability Scale: Past, Present, and Future," *Intl. J. Human-Computer Interaction* 34, no. 7 (2018): 577–90.
[79] Yow, *Recording Oral History* (n. 65), 82.

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participants as co-intellectuals and provide the space for them to share insights as experts on modern prosthesis use.

The integrative component of our method creates a plan of action to experiment with a model of a historical prosthesis, but it is also a productive intellectual exercise. Creating abstract tasks for an upper-limb prosthesis, for example, focuses attention on the position, grasp, and movement of hands. While formulating historically contextualized ADLs stimulates this form of thinking about individual activities, experiment design prods one to contemplate *patterns* of movement. Significantly, it concentrates attention on a historical wearer's possible experiences using a specific prosthetic artifact to perform an activity.

Conclusion

This article presents four components of a method to create and design experiments for a 3D-printed model of a historical prosthesis as discrete parts. However, our experience of them was often interactive and overlapping. Our considerations of what was possible with the Kassel Hand while developing ADLs cannot be untangled from the team talking through problems with our first prototype. So it went with experiment design itself: we had a second prototype to think with as we brainstormed hand movements, and designing experiments pointed us to further refine the prototype. For instance, once we decided to attempt a chest lid lift as an abstract task, we started discussing how to strengthen our model's plastic shell to better match the performance of the artifact's iron one. The stages of work we describe build on and influence one another, creating a coherent form of object-based historical investigation.

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Ultimately, our method generates the intellectual and physical tools needed to explore the lived experience of amputees through physical interactions with devices. Experimental assessments of historical prostheses suggest a way to overcome the challenges of physically testing fragile artifacts. Focusing the manufacturing process on 3D printing creates a cost-effective and shareable model. As modern assistive devices and wearables become ubiquitous, designing a historical investigation that taps into growing trends in 3D manufacturing of prosthetics and orthotics also increases opportunities to locate collaborators. Furthermore, each component of the method is itself generative. It builds on a scholar's encounter with an artifact to reflect on its wearer's experiences in new ways. In our case study of an upper-limb prosthesis, this brought heightened attention to the cultural and practical significance of whether the object was a right or left hand, of which fingers moved and how. The journey preparing tools for testing is fruitful.

Of course, the destination is significant, too. Once all four components of the method are complete and experiments thoughtfully designed, one can actually run them.

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