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Designing Piano Technique: A Historical and Industrial Design Analysis of Piano-Playing Aids From 1814 to the Present

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ABSTRACT
This study examines piano-playing aids documented from 1814 to the present from an industrial design history perspective. Thirty-four product configurations, documented through October 2026 and identified from patents, method books, period advertisements, museum records, manufacturers' documentation, and academic publications, were compared in terms of problem framing, bodily intervention, adjustability, feedback, skill transfer, and type of evidence. The findings show that these aids did not develop linearly from mechanical to digital technologies. Physical guides, resistance devices, silent practice keyboards, ergonomic adaptations, accessibility systems, computational feedback, and robotic prototypes instead embody different historical design approaches within the same product field. The study conceptualizes these products as materialized pedagogy, through which pedagogical ideas are translated into material or computational features. The principal historical transformation was an expansion of intervention across the body, instrument, interface, and instructional system. The results indicate that technical function, pedagogical claim, and scientific evidence should be distinguished, while user autonomy, bodily diversity, accessibility, and skill transfer should be evaluated together. The study accordingly proposes a conceptual qualitative industrial design evaluation framework for piano-playing aids, illustrated through three cases but not empirically validated.
Keywords: piano-playing aids, industrial design, design history, materialized pedagogy, accessibility, bodily diversity

Piyano Tekniğinin Tasarımı: 1814'ten Günümüze Piyano Çalma Yardımcılarının Tarihsel ve Endüstriyel Tasarım Açısından Analizi

ÖZET
Bu çalışma, 1814'ten günümüze belgelenen piyano çalma yardımcılarını endüstriyel tasarım tarihi açısından incelemektedir. Ekim 2026'ya kadar belgelenen, patentler, yöntem kitapları, dönem ilanları, müze kayıtları, üretici belgeleri ve akademik yayınlardan belirlenen 34 ürün konfigürasyonu; problem tanımı, bedensel müdahale, ayarlanabilirlik, geri bildirim, beceri aktarımı ve kanıt türü bakımından karşılaştırılmıştır. Bulgular, bu yardımcıların mekanikten dijitale doğrusal bir gelişim izlemediğini göstermektedir. Fiziksel kılavuzlar, direnç araçları, sessiz çalışma klavyeleri, ergonomik uyarlamalar, erişilebilirlik sistemleri, hesaplamalı geri bildirim ve robotik prototipler aynı ürün alanında farklı tarihsel tasarım yaklaşımlarını sürdürmektedir. Çalışma, bu ürünleri pedagojik düşüncelerin maddi veya hesaplamalı özelliklere dönüştürüldüğü "maddileştirilmiş pedagoji" olarak kavramsallaştırmaktadır. Temel tarihsel dönüşüm, müdahale alanlarının beden, enstrüman, arayüz ve öğretim sistemi boyunca genişlemesidir. Sonuçlar, teknik işlev, pedagojik iddia ve bilimsel kanıtın ayrıştırılması; kullanıcı özerkliği, bedensel çeşitlilik, erişilebilirlik ve beceri aktarımının ise birlikte değerlendirilmesi gerektiğini göstermektedir. Çalışma bu doğrultuda piyano çalma yardımcıları için üç vakada örneklendirilen, ancak henüz ampirik olarak doğrulanmamış kavramsal ve nitel bir endüstriyel tasarım değerlendirme çerçevesi önermektedir.
Anahtar kelimeler: piyano yardımcıları, endüstriyel tasarım, tasarım tarihi, maddileştirilmiş pedagoji, erişilebilirlik, bedensel çeşitlilik

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1. INTRODUCTION: DESIGNING PIANO TECHNIQUE

Piano playing is a complex embodied skill requiring the simultaneous coordination of auditory perception, visual score reading, and multi-joint motor actions. Technical proficiency depends not only on independent finger movement but also on coordination among the hand, wrist, forearm, elbow, and torso. Expert pianists employ movement strategies that vary according to musical context and performance demands rather than reproducing fixed patterns (Furuya & Altenmüller, 2013). Piano technique is therefore shaped through the continual reconfiguration of the relationship among body, instrument, and task.

Since the early nineteenth century, numerous products have been developed to guide hand position, promote finger independence, increase strength, extend range of motion, or support technical practice away from the instrument. These include wrist supports, finger guides, resistance devices, silent practice keyboards, alternatively sized keyboards, and digital feedback systems. Their shared characteristic is the translation of assumptions about technical development into physical or computational systems.

Although primarily regarded as pedagogical tools, piano-playing aids are also designed objects that embody particular models of users, bodies, and behaviors. Their form, dimensions, mechanisms, contact points, adjustment systems, and use scenarios encourage certain movements, constrain others, and establish the conditions under which practice occurs. These characteristics reveal how appropriate technique is defined, which movements are considered in need of development, and how users are expected to achieve the intended outcome.

Piano-playing aids should therefore be understood as design interventions in the relationship between body and instrument. A wrist rail defines an acceptable range of movement, a resistance mechanism frames technical development through strength and repetition, and an alternatively sized keyboard locates mismatch in the standardized dimensions of the instrument rather than solely in the user's body. Camera-based systems convert movement into measurable data and connect technical assessment to computational models.

Within piano pedagogy, these products have generally been addressed as components of teaching methods or historical approaches to technique (Gerig, 2007). Their design characteristics, ergonomic assumptions, user experiences, and effects on behavior have received comparatively limited attention. Yet they constitute significant sources for design history because they reveal how different periods conceptualized the body, located technical problems, and translated pedagogical decisions into products.

Their historical development reflects changes not only in mechanisms but also in how pianist–instrument fit has been configured. Some products sought to bring the user's body towards a predetermined technical norm, while others adapted the product, instrument, or practice environment to different users. Physical guidance was later supplemented by movement measurement, computational assessment, and robotic support. These approaches did not form successive stages in which one model replaced another. Normative guides, resistance devices, accessibility solutions, and digital feedback systems continue to coexist.

This article examines piano-playing aids documented from 1814 to the present from the perspective of industrial design history. It investigates how the technical and pedagogical approaches of different periods were translated into product forms, mechanisms, instrument dimensions, feedback arrangements, and use scenarios. The products are treated as design systems that configure the pianist–instrument relationship by intervening in different components of that relationship.
The principal research question is:

Through which design decisions have products developed to support piano playing materialized the technical and pedagogical assumptions of different periods, and how have these products configured the pianist–instrument relationship?

Three subsidiary questions are addressed:

1. How have piano-playing aids framed the technical problem and intended user in relation to the body, instrument, interface, or instructional system?
2. Through which design strategies have objectives such as finger independence, strength, flexibility, access, movement control, and feedback been translated into product features?
3. How has design responsibility been distributed historically among the user, assistive product, piano, teacher, and computational systems?

The study does not interpret technological change as a linear narrative of progress. Historical products are approached as material or computational expressions of different conceptions of the body, models of learning, and design approaches. Rather than ranking products as successful or unsuccessful, the study compares how they frame technical problems, direct user behavior, and configure the pianist–instrument relationship.

The corpus encompasses devices attached to the piano, independent exercise devices, silent practice keyboards, movement-measurement apparatuses, alternatively sized keyboards, accessibility supports, computational tutoring systems, and robotic research prototypes. The analysis considers their intended users, assumed forms of bodily use, enabled or constrained movement possibilities, assumptions about skill transfer, and supporting evidence. Here, "piano-playing aid" is the umbrella term; "training device" denotes a learning or conditioning objective, "accessibility system" denotes sustained access to playing, and "research prototype" identifies development status rather than a user group. These categories may overlap.

Drawing on piano pedagogy while situated primarily within design history, product–user interaction, ergonomics, and inclusive design, the study approaches piano technique not only as a learned skill but also as an experience materialised and reconfigured through products, instruments, instructional systems, and user practices. The following section establishes the conceptual basis for this analysis by examining technical knowledge, product mediation, anthropometric diversity, and the distribution of design responsibility.

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1. Designing Piano Technique: The Body, Movement, and Technical Knowledge

Approaches to piano technique have changed alongside assumptions about how the body should be used. Early schools emphasized hand position and finger independence, whereas later approaches gave greater importance to arm weight, rotation, relaxation, and integrated movement coordination (Gerig, 2007). Technical knowledge should therefore be understood not as a fixed set of rules but as a historical construct shaped by period-specific conceptions of the body.

This transformation is also evident in piano-playing aids. Hand-guiding apparatuses, resistance systems, silent practice keyboards, and movement-measurement devices embody assumptions about which movements pianists should learn, the variables through which development should occur, and who should define appropriate technique. Their forms, mechanisms, and use arrangements can thus be read as material manifestations of technical thought.

Ortmann's (1929) research marked an important shift by examining movement mechanics, force transfer, and observable physical variables rather than relying solely on teachers' experience or traditional authority. It distinguished pedagogical claims from bodily effects, a distinction equally necessary when evaluating piano-playing aids. A product's capacity to produce or constrain movement does not demonstrate that the user has learned it, just as

resistance does not prove that increased strength transfers to piano performance. Technical function, pedagogical interpretation, and claimed musical outcome are related but distinct levels of evaluation.

Piano-playing aids are therefore treated as designed objects through which technical knowledge is produced, standardized, and communicated in product forms and use scenarios.

2.2. Product Mediation and the Shaping of the User

Industrial design research approaches products not as passive tools but as mediators that encourage, guide, or constrain action. Technological objects shape how users relate to their environments and actions (Verbeek, 2005). A wrist support may encourage a particular position, a resistance mechanism may define development through strength and repetition, an alternatively sized keyboard may locate difficulty in instrument dimensions, and a camera-based system may connect movement assessment to a computational model.

Products therefore convey not only technical knowledge but also particular modes of use and user roles. Akrich's (1992) concept of the script explains how technical objects anticipate who users are, the sequence of their actions, the feedback they follow, and the decisions they can make independently.

Scripts also encompass contexts of use. The same mechanism may acquire different meanings under teacher supervision, during individual practice, or within a digital instructional system. Fallan's (2008) approach to design history consequently calls for objects and contexts to be examined together. Product form, teaching method, practice programme, distribution model, and user experience cannot be fully separated.

Norman's (2013) concepts of constraints, mapping, and feedback further clarify these interactions. Products may reduce movement options, generate resistance, or provide auditory, visual, or tactile cues without preventing movement. Their differences therefore concern not only the problems they address but also the interaction models through which they construct their solutions.

Piano-playing aids are thus design interventions in the relationship between body and instrument. Design supports technical practice while also shaping the movements, criteria, and forms of feedback through which that practice is conducted.

2.3. Ergonomics, Anthropometric Diversity, and Design Strategies

Many piano-playing aids seek to adapt users to a technical norm, whereas others adapt the product or instrument to the user. This distinction concerns user-product fit and the limitations of designing around a single average user. Hand span, finger length, joint mobility, and muscular capacity vary, making the same product functional for some users but restrictive or unnecessarily demanding for others (Dreyfuss, 1955; Pheasant & Haslegrave, 2005).

Standard keyboard dimensions likewise do not create equivalent physical conditions for all pianists. Relationships among keyboard size, hand span, finger position, and muscular activity vary with user characteristics (Chi et al., 2021; Deahl & Wristen, 2017). Technical development therefore cannot be understood solely as the user adapting to the existing instrument.

The design question concerns not only how the user should change but also which elements of the product, instrument, or environment can be altered. While some historical aids sought to bring the body towards a prescribed norm, alternatively sized keyboards, adjustable pedals, and accessibility supports reconsider the interface on which that norm depends.

Ergonomic fit must nevertheless be distinguished from making the musical task easier. A keyboard adapted to the user's hand does not eliminate the demands of rhythm, articulation, coordination, tone control, or interpretation. It may instead reduce physical demands that are not integral to the musical task.

Ergonomics is therefore approached as a design problem concerning the bodily characteristics against which proficiency is defined, the users privileged by a standard, and the component altered to establish pianist–instrument fit. Inclusive design similarly treats user diversity as an initial design input. This does not require one product for all users, but an appropriate combination of shared features, adjustable components, size options, and individually tailored solutions.

2.4. Conceptual Framework: Materialized Pedagogy and Configuring the Pianist–Instrument Relationship

This study considers piano-playing aids as material or computational expressions of pedagogical and technical thought. Technical knowledge resides not only in instructional texts, teachers' explanations, and performance traditions, but is also produced through product forms, mechanisms, contact surfaces, adjustment systems, and feedback rules.
Materialised pedagogy refers to the embodiment of technical and pedagogical propositions in design features. Instructions such as "avoid dropping the wrist," "develop finger independence," or "maintain balanced posture" may be translated into rail height, separate springs, or a footrest, while "perform the correct movement" may become a computational classification rule.

This process is neither a direct nor lossless transfer of pedagogical thought. Products select aspects of pedagogical knowledge that can be converted into manufacturable or computational features, potentially excluding context-dependent aspects. An instruction that a teacher adjusts according to fatigue, repertoire, or bodily characteristics may become a generalized mechanical rule. A computational system may similarly centre technical assessment on only those variables it can detect.

Materialized pedagogy is used here as a domain-specific analytical lens, not as a replacement for technological mediation, scripts, or affordances. Mediation concerns how technologies shape action; scripts concern anticipated users and conduct; affordances concern possibilities for action. The additional focus here is the translation from a teaching proposition to a design feature, the aspects of embodied instruction lost in that translation, and the evidence needed to connect the feature to learning (Akrich, 1992; Norman, 2013; Verbeek, 2005).

Configuring the pianist–instrument relationship refers to establishing that relationship by altering different components. Some products expect change in the user's body; others adapt the product or instrument, modify the practice environment, or transfer part of the assessment function from the teacher to a feedback system. Design responsibility is consequently distributed among the user, product, instrument, teacher, researcher, and computational system.

Historical products are examined across five dimensions:

1. Framing of the technical problem: Which deficiency, mismatch, or developmental need does the product address?
2. Mode of bodily intervention: How is movement constrained, guided, supported, measured, or reconfigured?
3. Ergonomic approach: How are user diversity, bodily dimensions, and movement capacities addressed?
4. Skill transfer: How is product-supported practice assumed to transfer to actual piano-playing conditions and different musical tasks?
5. Configuration of the pianist–instrument relationship: Which component is expected to change, and among which actors is design responsibility distributed?

These dimensions are not intended to rank products as successful or unsuccessful. They identify the conceptions of the body underlying different design strategies, the ways these strategies direct behavior, the movement possibilities they enable or constrain, and the evidence supporting their claims.

Products are therefore compared not by technological advancement but by their problem framing, site of intervention, distribution of decision-making, and configuration of the pianist–instrument relationship.

3. METHOD AND PRODUCT CORPUS

3.1. Research Design and Construction of the Product Corpus

This qualitative, comparative design history study examines piano-playing aids documented from 1814 to the present. Rather than providing a comprehensive history of piano pedagogy or focusing on inventors' biographies, it investigates how technical and pedagogical objectives were translated into product forms, mechanisms, instrument dimensions, feedback arrangements, and use scenarios.

The unit of analysis is not limited to the physical object. Each case is approached as a design configuration comprising the product, user, musical task, mode of use, pedagogical objective, relationship with the teacher, and conditions of commercial or institutional circulation. This enables comparison between similar mechanisms used for different purposes and physically dissimilar products embodying shared design strategies.

The research draws on the comparative logic of multiple-case study research (Yin, 2018), and approaches from material culture studies and design history (Fallan, 2008; Prown, 1982). Products are examined through their technical characteristics, anticipated user behaviours, sequences of use, and associated pedagogical or commercial systems.

The corpus begins with Johann Bernhard Logier's 1814 patent for the Chiroplast and extends to mechanical guides, independent exercise devices, silent practice keyboards, movement-measurement apparatuses, ergonomic and accessibility-oriented solutions, computational tutoring systems, and robotic research prototypes documented up to October 2026. The starting point is a deliberate historical boundary: Chiroplast links a documented apparatus with a teaching method and licensing system. It is not a claim that 1814 marks the first physical aid or the earliest surviving patent record. The French application for Logier's mechanism was filed by Galliani de Serri on 3 February 1819 and granted on 12 March 1819 (Institut national de la propriété industrielle, 1819, dossier 1BA1265; Figure 1a).

For reporting, the configurations discussed in Section 4 are enumerated as C01–C34 in Tables S1 and S2 in the Appendix. Related patents and variants are counted together for the Saboia support, DS Standard, Steingraeber systems, Ortmann apparatuses, and children's aids; Kalkbrenner's associated practice keyboard is included in his product family. The four narrative groups contain 5, 4, 15, and 10 configurations respectively. These are thematic placements, not mutually exclusive invention-date intervals. Documentation varies, so the common questions do not imply equal analytical depth. Yamaha HS-500 and the three general-purpose resistance products are boundary or contextual comparisons, distinguished from the 30 piano-specific configurations. The comparative patent illustrations in Figures 6–8 clarify mechanisms within these categories. They do not increase the case count.

To be included in the corpus, a product was required to meet the first two of the following criteria, supported by an analyzable record as specified in the third; the final two guided purposive selection:

1. Documentary evidence that it was developed for or marketed to piano students, pianists, or piano teachers

2. A physical or computational intervention in the user's body, piano interface, practice behavior, or instructional process
3. An analyzable patent, object, image, usage document, or research record concerning its structure, use, or pedagogical purpose
4. Representation of a distinctive design strategy or historical continuity
5. Association with a teaching method, licensing arrangement, marketing strategy, distribution system, or service system

Scores, exercises, and method books without a corresponding product were excluded, and general-purpose devices were not treated as evidence of piano-specific adoption without a verified connection. Gripmaster, Varigrip, and Finger Weights are retained as contextual comparisons of resistance mechanisms; their musician-oriented marketing alone does not establish piano use.

The corpus was structured not as a chronological inventory, but to reveal different approaches to the pianist–instrument relationship. Products were compared through intervention strategies including positioning, resistance and stretching, silent practice, movement awareness and measurement, ergonomic support, instrument rescaling, accessibility, computational feedback, and robotic movement generation. The comparison includes contrasting and transitional cases: Jankó's alternative interface, persistent late mechanical guides, and experimental systems with unestablished commercial adoption. This supports analytical comparison, not statistical representativeness or a complete sample of commercial failures.

Chronological groupings identify prominent problem framings and design orientations rather than discrete stages in which newer products displaced earlier ones. This structure acknowledges the coexistence of normative mechanical guides, accessibility solutions, and computational systems within the same product field.

3.2. Sources and Evidence Structure

The research draws on patents, user manuals, method books, period advertisements, commercial catalogues, museum records, photographs of physical objects, academic publications, theses, manufacturers' documentation, and institutional records. These sources were not treated as having equivalent evidential value. Each makes a different aspect of the product visible.

The cited records are hosted in BnF/Gallica, the Smithsonian, Musée de la musique, Powerhouse, the Library of Congress, INPI, patent repositories, ERIC, the University of Maryland repository, periodical collections, and publishers' or manufacturers' sites. These identify the documentary locations represented in the corpus; they should not be read as evidence that every collection was exhaustively searched. Table S1 in the Appendix links each configuration to its record or publication.

The documentary search was conducted in September and October 2026. Searches were conducted in English, beginning with known product and inventor names and descriptive terms such as "Chiroplast," "Dactylion," and "piano pedal extension." Books, journal articles, and historical periodicals were used to identify an initial set of cases. Related patent documents and museum collection records were then consulted to verify product identities, dates, and documented features where possible. Sources in languages other than English and Turkish were consulted using browser-based translation into English.

Candidate records were assessed against the criteria in Section 3.1. Primary documents were preferred when establishing product identity and date. Alternative names and related versions were matched using product names, inventor or maker names, patent identifiers, and collection records where available. Patents, advertisements, and collection records were used to establish different aspects of each case. Claims about pedagogical or

ergonomic effects were assessed against research evidence where available. Tables S1 and S2 record the documentary basis and the remaining uncertainties for each configuration. Patents document proposed technical solutions, mechanical relationships, and anticipated modes of use, but do not establish manufacture, sales, widespread use, or effectiveness. Museum objects and collection records document the material, form, and physical existence of preserved examples without demonstrating prevalence. Period advertisements and commercial catalogues reveal intended users, pricing, distribution, and promised benefits. Claims concerning strength, flexibility, ideal hand form, or rapid learning were therefore interpreted as marketing discourse rather than independent evidence of effectiveness.

Method books and user manuals indicate the product's intended place within a practice programme and the behaviors expected of users. Manufacturers' documentation provides information about contemporary products and intended use scenarios, but was not substituted for independent research findings.

Academic studies were used to assess biomechanical or pedagogical effects within specific tasks and user groups. Their findings were interpreted in relation to research design, sample, task, duration, and measurement method. Short-term changes in muscular activity were not treated as long-term health outcomes, immediate performance improvements as retained learning, or successful single-user cases as broadly generalizable results.

Visual materials were analyzed as evidence rather than treated solely as illustrations. Patent plates informed the analysis of mechanical relationships, advertisements revealed commercial and social presentation, usage photographs documented body–product contact, and museum photographs supported the examination of materials and construction. Following Rose (2016), the contexts and purposes of image production were considered alongside visual content.

Four evidential categories are distinguished: documented characteristics; inventor, manufacturer, or advertiser claims; research findings (with independence assessed separately); and interpretations developed through the present design framework. A spring may be verified through the force it applies, a camera through the movement it tracks, and a robotic apparatus through the movement it generates. Claims concerning learning, skill transfer, or health outcomes require additional evidence.

Commercial circulation was assessed, where possible, through catalogues, price lists, sales records, recurring advertisements, and documentation of institutional use. Documents lacking an identifiable source, publication place, or date were retained as boundary records but were not used as primary evidence for chronology, prevalence, or effectiveness.

This evidence structure is intended to prevent design intent, physical existence, commercial presentation, user experience, pedagogical effect, and scientific findings from being treated as equivalent forms of evidence.

3.3. Analytical Framework and Comparative Analysis

The analytical framework examines both product function and how products reconfigure the relationship between user and piano. Products were approached as design structures mediating interaction between body and instrument (Verbeek, 2005). Their constraints, forms of guidance, and feedback were assessed from an interaction design perspective (Norman, 2013), while assumptions concerning the user's body were interpreted through ergonomics and anthropometry (Dreyfuss, 1955; Pheasant & Haslegrave, 2005).

For each case, the product name, date, designer or manufacturer, patent or object status, and associated publications were recorded. A common analytical framework was then applied across the following dimensions:

1. Technical problem and mismatch identified
2. Intended user and context of use
3. Assumptions concerning the user's body
4. Points of contact between product and body
5. Attachment to or integration with the instrument
6. Principle of intervention, including constraint, resistance, support, measurement, feedback, or actuation
7. Mechanism and material arrangement
8. Adjustment, personalization, and deactivation
9. Use scenario and the teacher's role
10. Distribution of control among the user, teacher, product, and computational system
11. Claimed technical, pedagogical, or ergonomic benefit
12. Assumptions concerning skill transfer
13. Type and limits of the evidence supporting the claim

The framework was not used to rank products through standardized scoring. Its purpose was to establish comparable design relationships across historical and contemporary cases, from the Chiroplast to alternatively sized keyboards, computational feedback systems, and robotic prototypes.

The comparative analysis focuses on how products established pianist–instrument fit. Some sought to bring the user's body towards an existing norm. Others reshaped instrument dimensions, support surfaces, or control arrangements. Computational systems transferred part of movement assessment from the teacher to measurement and feedback systems.

Historical transformation was therefore evaluated through the component expected to change and the distribution of design responsibility, rather than technological novelty alone. The central question is how each product framed the technical problem, which movements it enabled or required, and how it distributed responsibility among the user, product, instrument, teacher, and feedback system.

Skill transfer was treated as a separate analytical dimension. A product's capacity to regulate movement during use does not establish that the movement can be sustained without it. Temporary pedagogical supports were therefore distinguished from continuous accessibility supports. Teaching aids may require the gradual withdrawal of support and transfer to unaided performance. Accessibility aids may instead be evaluated according to the reliable and sustained musical participation they enable while in use.

Technical function, usability, intended outcome, and skill transfer were treated as distinct evidential levels. Patents, advertisements, and manufacturers' statements were not considered sufficient evidence of pedagogical or health-related effectiveness. No ergonomic, pedagogical, or clinical claims were made for products lacking independent experimental evidence.

Historical cases were first examined within chronological and thematic groupings, after which their intervention strategies were compared through a cross-period design matrix. This made visible both the coexistence of different approaches within the same period and the reappearance of earlier mechanical principles through new materials, manufacturing methods, or feedback systems. Table S2 in the Appendix makes the case-level comparison inspectable, including construction, contact, control, transfer, and evidential gaps. Materials, dimensions, manufacture, maintenance, and appearance are recorded only where documented; unspecified attributes remain unknown.

The research is limited to surviving documents and objects. Archival preservation, institutional collecting, and digitization may have made certain products more visible than others, while the density of documentation does not necessarily indicate widespread use.

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The study includes no new user trials. Its evaluations are based on the combined analysis of historical sources, product attributes, and relevant literature.

4. THE HISTORICAL TRANSFORMATION OF PIANO-PLAYING AIDS: CONFIGURING THE PIANIST–INSTRUMENT RELATIONSHIP

The historical analysis traces how piano-playing aids configured pianist–instrument fit through changing sites and modes of intervention. Early products prescribed hand and wrist positions, while later approaches addressed physical capacity, movement measurement, anthropometric diversity, instructional systems, accessibility, and robotic support. Rather than replacing one another, these approaches accumulated within the same product field. The analysis therefore follows shifts in problem framing, bodily intervention, pedagogical authority, and criteria of success.

4.1. Positioning the Body and Developing Physical Capacity: 1814–1885

Products developed during the first half of the nineteenth century approached elementary technique primarily through the positioning of the hand and wrist. Johann Bernhard Logier's Chiroplast, patented in 1814, constrained movement through wrist rails and finger guides attached to the keyboard. Instructions concerning hand level, wrist height, and finger position were thus translated into product geometry (Logier, 1816; Taylor, 1900a).

The Chiroplast also operated as part of an early product-service system combining graded lessons, instructional materials, group teaching, teacher licensing, and commercial distribution (Rainbow, 1990). In design terms, the apparatus can be interpreted as delegating part of positional guidance from the teacher to its geometry; this is not a measured reduction in teaching effort. Its predefined wrist height, finger spacing, and movement direction nevertheless sought to bring different bodies towards a shared technical norm.

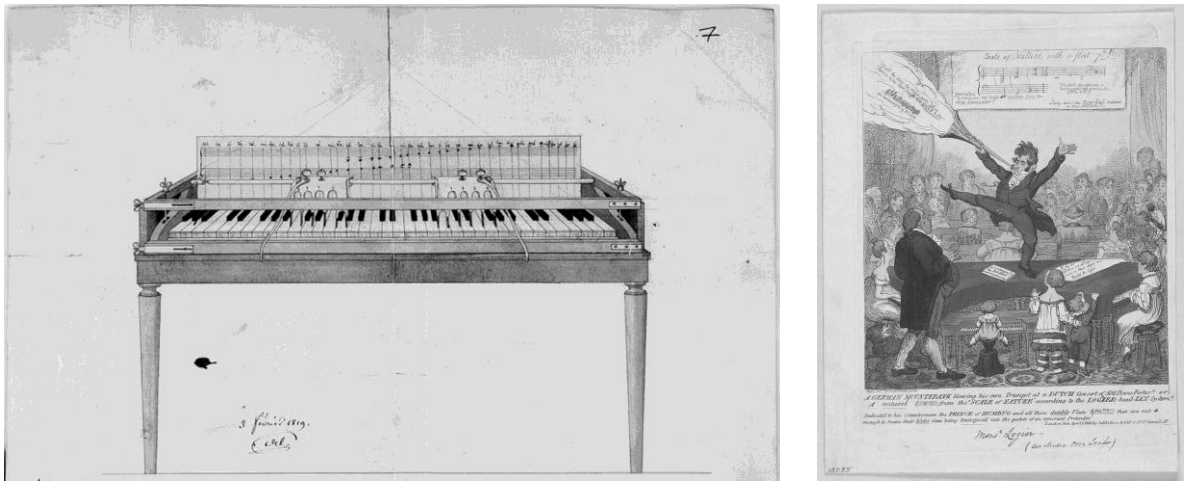


Figure 1. The Chiroplast's design and public reception: (a) French patent drawing, application filed by Galliani de Serri on 3 February 1819 for Logier's mechanism (Les archives de l'INPI, dossier 1BA1265; public domain); (b) Cruikshank's The Logierian System (1818), Library of Congress, LC-DIG-ds-01348 (no known restrictions on publication).

Friedrich Kalkbrenner's Hand Guide, associated with his nineteenth-century method, retained this problem framing while simplifying the intervention. It replaced separate finger channels with a horizontal support that established forearm height, returning a greater degree of movement control to the user and teacher (Kalkbrenner, n.d.). Its reduced number of components suggests simpler setup for domestic practice, although comparative usability is not documented. Kalkbrenner's inclusion of a portable silent practice piano within the same method further expanded the approach from a single apparatus to a small product family. Saint-Saëns's (1919) criticism indicates a pedagogical dispute about its

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compatibility with integrated arm movement, rather than a tested limit applying to all repertoire.

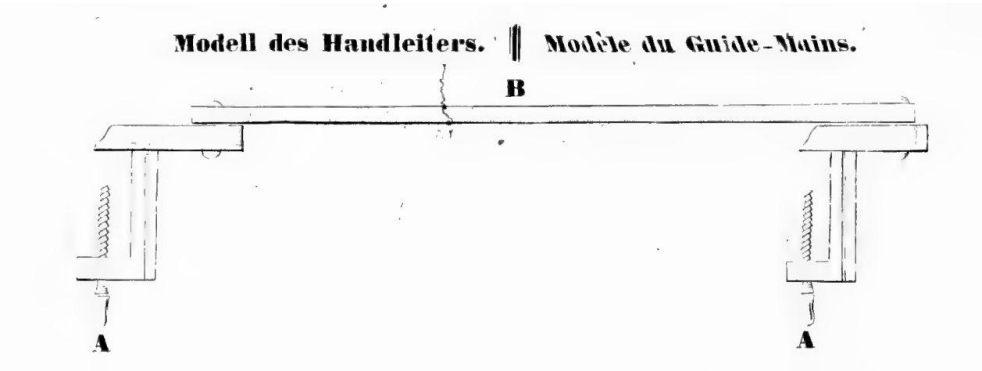
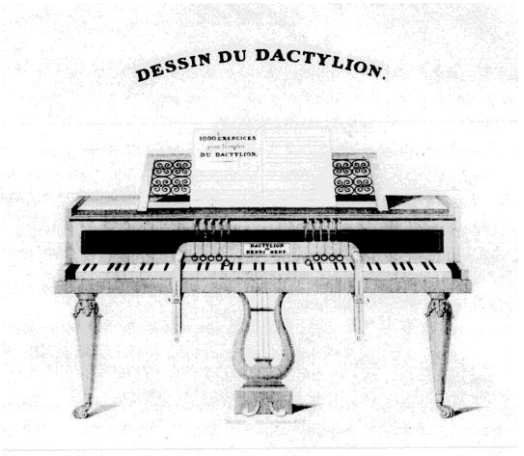


Figure 2. Kalkbrenner's Hand Guide, showing the horizontal support bar and its two mounting brackets. Source: Kalkbrenner (1832, p. 28), "Modèle du Guide-Mains" (public-domain excerpt, University of North Carolina at Chapel Hill Libraries).

From the mid-1830s, the design problem shifted from maintaining position to developing strength, independence, flexibility, and endurance. Henri Herz's Dactylion applied separate spring resistance to each finger while the user played an actual piano key. It thereby transformed piano movement into conditioning exercise performed against additional resistance. Herz's accompanying exercises organized technical development through exercise selection, load, repetition, and practice duration, although the surviving documentation does not specify how resistance was to be matched to individual capacity or how overuse was to be avoided (Herz, 1836).

Levacher d'Urclé's Assouplisseur de doigts treated finger span and flexibility as problems that could be trained away from the instrument, excluding sound, key response, and timing from the practice task (Levacher d'Urclé, 1846). Myer Marks's Digitorium subsequently transferred a similar conditioning model into a portable box with five resistant keys. Because its resistance exceeded that of contemporary piano keys, the Digitorium did not simulate piano touch. Taylor (1900b) accordingly described it as a finger-gymnastics device rather than a substitute keyboard. Its advertisements promised strength, evenness of touch, increased span, and rapid improvement, but these promises document commercial positioning rather than independently demonstrated effects. The preserved Digitorium is catalogued as timber, ivory, and metal, 69 × 162 × 210 mm; this documents compact construction, not the scale of adoption (Powerhouse Collection, n.d.).



THE DIGITORIUM (Patent).—Every requisite to attain in an incredibly short time proficiency in playing on the Pianoforte, Organ and Harmonium, is acquired by a short practice on this remarkable and popular invention. Evenness of touch, flexibility of finger, strength of wrist, position of the hand and stretch of octave, are acquired by its use.

TO SCHOOLS the DIGITORIUM is invaluable. Immense saving in the wear of the Piano is effected. A substitute where there is no Piano, and for travelling. Mr. John Adlington, Prof. Mus., Choirmaster of St. Andrew, Organist to the Bishop of Aberdeen, writes—"It fully realises all that has been said in its favour. I have introduced it into several schools and families with great success."

THE DIGITORIUM (Patent). — Mr. Charles Hallé writes—"I consider the Digitorium a valuable invention." Mr. Brinley Richards—"One of the most simple and useful inventions I have yet seen" Dr. Rimbault, F.R.S., Musical Examiner to the College of Preceptors—"The practical utility of the Digitorium must be apparent at a glance to all who consider the subject with the least attention."—Forwarded in case (with

Figure 3. Two documentary views of conditioning aids: (a) the Dactylion mounted on a piano, from Herz (1836), "Dessin du Dactylion," Bibliothèque nationale de France, Gallica, btv1b10861680n, view 4 (public-domain excerpt); (b) Digitorium advertisements ("Digitorium Advertisements," 1869, p. 230; excerpt).

Online Journal of Art and Design
volume 15, issue 2, April 2027
DOI: https://doi.org/10.30935/ojad/2513147

During this period, pianist–instrument fit was configured primarily by altering the body. The Chiroplast and Hand Guide sought to produce appropriate positioning, while resistance and stretching devices sought to develop the physical capacities considered necessary. The fixed dimensions and mechanism of the piano itself remained largely outside the design problem.

4.2. From Alternative Interfaces and Training Platforms to Measurement and Feedback: 1882–1930

A parallel intervention emerged through Paul von Jankó's alternative keyboard, designed in 1882 and incorporated into commercially produced pianos by the late nineteenth century. Rather than training the user to accommodate the conventional keyboard, the Jankó system reorganized the interface as a multi-row array in which related key positions were repeated across the keyboard. This geometry altered established spatial and fingering relationships, requiring pianists to learn a new playing system and limiting transfer to conventional instruments. The design therefore demonstrates that reconfiguring the instrument may reduce one form of mismatch while creating new demands of learning, compatibility, and circulation (National Museum of American History, n.d.-a).

Alongside this interface redesign, the piano-playing aid also expanded from a device targeting a single movement into a multifunctional training platform. James Brotherhood's 1885 Technicon combined finger lifting, stretching, resistant key movement, and wrist and forearm exercise within one structure (Brotherhood, 1885). Adjustable springs, rings, levers, and weights provided different loads, but no standardized measurement system indicated how resistance should be selected. The teacher or user therefore remained responsible for determining an appropriate load. Its marketing as the "Pianist's Hand Gymnasium" framed the pianist's hand as a bodily system trainable through specialized equipment, while separate teacher and student models differentiated professional and educational markets ("Brotherhood Technicon," 1897).

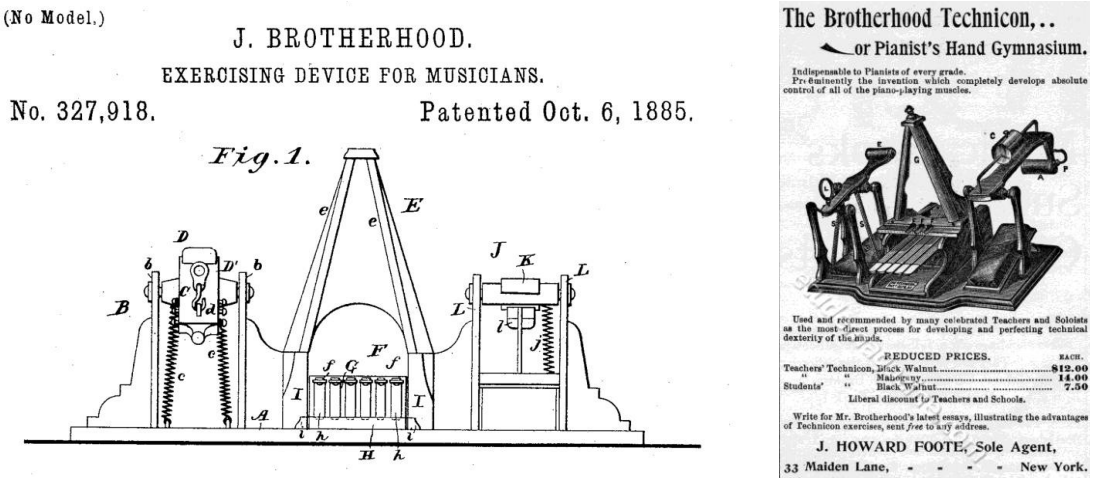


Figure 4. The Technicon's construction and marketing: (a) exercise stations mounted on a shared base (Brotherhood, 1885, US327918A, Fig. 1; excerpt); (b) period advertisement showing teacher and student models ("Brotherhood Technicon," 1897, December).

Almon Kincaid Virgil's Practice Clavier returned technical practice to the keyboard while removing the hammers, strings, and soundboard. Mechanical clicks generated during key depression and release made movement timing audible, enabling users to evaluate selected aspects of their actions without physically preventing them (Virgil, 1886). The product did not reproduce piano sound or provide quantitative measurement. Instead, it functioned as a specialized practice interface combining adjustable resistance with auditory feedback. Virgil's exercises and the associated manufacturing company integrated mechanism and instructional content within a shared product system (Virgil, 1895). The preserved example has a folding stand, documenting storage provision; its labelled

Online Journal of Art and Design
volume 15, issue 2, April 2027
DOI: https://doi.org/10.30935/ojad/2513147

restriction on the up-click setting records an operating instruction, not independently established safety (National Museum of American History, n.d.-c).

Otto Ortmann's research marked a more fundamental reversal in the relationship between mechanism and body. His laboratory apparatuses recorded finger, hand, wrist, and arm movements rather than forcing the body into prescribed positions. Pantographs, mechanical linkages, photography, and rotating recording surfaces transformed movement into curves, traces, and images that could be compared (Ortmann, 1925, 1929).

In an exercise apparatus, the mechanism applied force to the body. In Ortmann's measuring systems, the body activated the mechanism, which then recorded movement. Technical propositions consequently began to draw on observable records alongside pedagogical authority and bodily sensation. This did not eliminate normative technique, but changed the evidence through which it was justified. The apparatuses nevertheless represented only selected aspects of movement: pantographs recorded particular planes, photographs particular viewpoints, and force-measuring systems particular mechanical relationships.

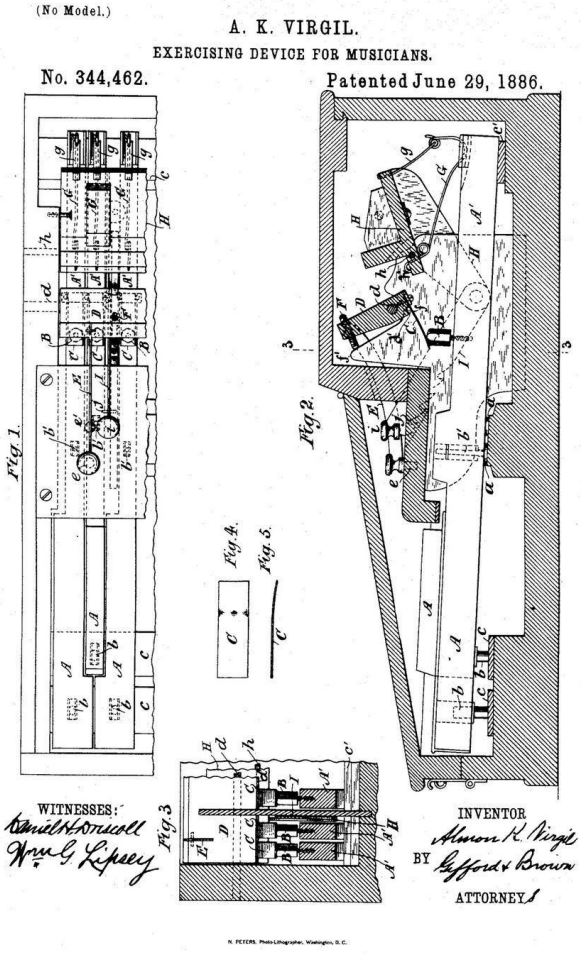


Figure 5. Virgil's drawings of the practice keyboard and its spring mechanism. Source: Virgil (1886), US344462A (plate excerpt).

The role of the piano-playing aid thus expanded beyond the production of physical capacity to include the organization of practice, immediate feedback, and the transformation of movement into research data. Design responsibility became distributed among product geometry, the user, the teacher, the experimental protocol, and the researcher's interpretation.

Online Journal of Art and Design
volume 15, issue 2, April 2027
DOI: https://doi.org/10.30935/ojad/2513147

4.3. From the Body to the Interface and the Instructional System: 1930–2010

Between 1930 and 2010, resistance devices continued alongside products addressing anthropometric access, classroom communication, kinaesthetic awareness, accessibility, instrument dimensions, and computational instruction.

The Magic Finger Developer transferred resistance from a tabletop apparatus to a wearable elastic system. Its portability expanded the practice environment, but decisions concerning strap position, elastic length, and tension remained with the teacher or user. Advertised improvements in touch and technique represented commercial claims rather than independent findings ("Magic Finger Exerciser," 1938a, 1938b).

Children's aids shifted the problem from physical capacity to anthropometric access. Adjustable music stands, footrests, and pedal extensions brought the fixed contact points of an adult-sized piano closer to child users. These products sought to establish the physical conditions for balanced posture and access rather than to strengthen or constrain the body ("Jenkins Children's Piano Aids," 1948).

The Wurlitzer Music Laboratory extended assistance from the individual body to the classroom. Its network of teacher console, student pianos, headphones, microphones, and communication channels organised the teacher's attention and the auditory environment (Kent, 1970). The system increased the scale of communication, although it could not assess bodily movement in comparable detail.

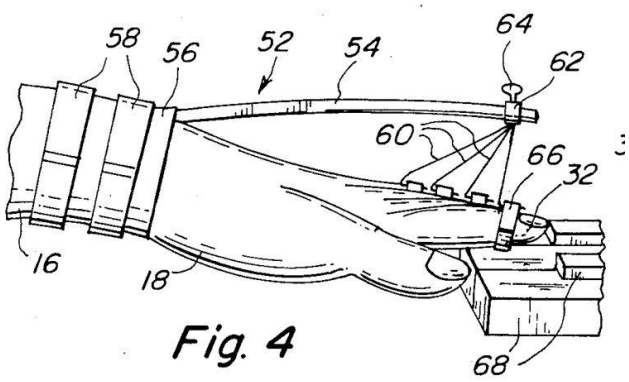


Fig. 4

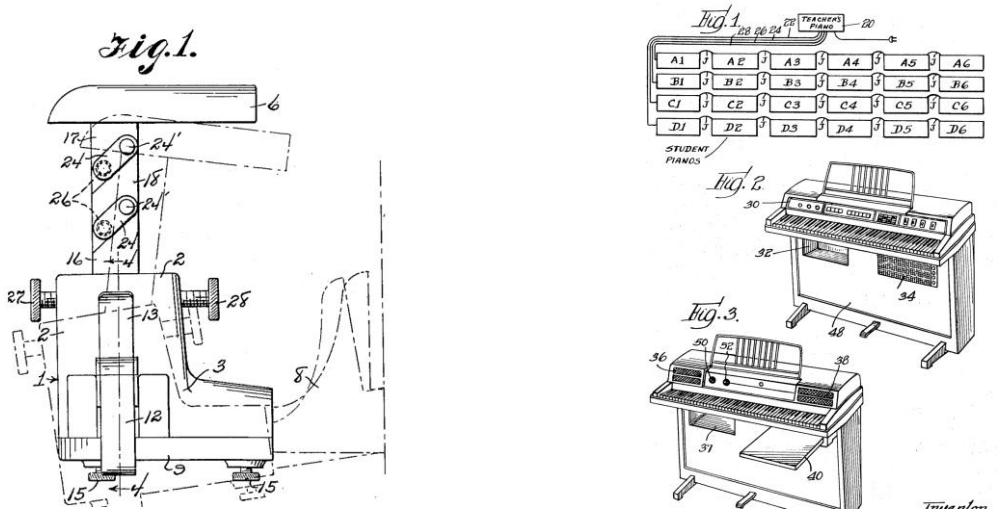


Figure 6. Original patent drawings illustrating three scales of intervention: (a) individual practice, Bonasera's wearable finger exerciser shown in keyboard use (Bonasera, 1988, US4765608A, Fig. 4); (b) children's playing setup, Sappenfield's piano pedal extension (Sappenfield, 1936, US2047332A, Fig. 1), a comparison with the pedal aids discussed in the text; (c) group instruction, Andersen's Wurlitzer system with teacher and student pianos (Andersen, 1971, US3584530A, Figs. 1–3).

From the 1970s onwards, physical constraint, resistance, kinaesthetic awareness, and electronic instruction continued to coexist. Harrington's rigid apparatus maintained predefined finger intervals, while the Mikimoto Finger-Board used individually positioned tactile surfaces to develop awareness of contact and unnecessary tension (Harrington, 1980; Hosaka, 2009). Bonasera and Niks continued to organize movement through elastic resistance and mechanical axes (Bonasera, 1988; Niks, 1989). The Finger-Board, by contrast, partially personalized product geometry and supported the perception of movement rather than mechanically fixing the body.

The Yamaha HS-500 transferred assistance from physical guidance to an electronic cycle of question, response, and verification. It evaluated pitch, note, and chord recognition while leaving hand movement and bodily comfort largely unobserved (Yamaha Corporation, n.d.). This contrast reveals a broader shift: mechanical products made the body visible but assessed musical outcomes only partially, whereas early electronic products assessed selected outcomes while leaving the body largely invisible.

Mechanical corrective devices nevertheless continued to be proposed after 1990. Patented wrist guides proposed maintaining prescribed positions through physical boundaries (Iwatani, 1995; Michelson & Maurer, 2007; Niks, 1992). Movable forearm supports developed by Saboia de Albuquerque and Sato instead proposed carrying part of the user's physical load and addressing keyboard access for users with different movement capacities (Saboia de Albuquerque, 1994, 1998; Sato, 2000).

The Donison–Steinbuhler Standard more explicitly reversed the conventional problem framing by rescaling key and octave widths rather than treating a smaller hand span as a bodily limitation. The design made visible that the standard keyboard advantages particular body dimensions. Experimental research later demonstrated user-dependent relationships among keyboard size, hand span, and muscular activity (Chi et al., 2021).

The Carnegie Mellon Piano Tutor represented another site of intervention. It combined the piano, sensing technology, software, lesson content, and multimedia within a computational tutoring system. The system generated feedback by comparing performance with recorded models, but its pedagogical capacity remained limited to measurable data. Finger choice, wrist tension, pain, and economy of movement were not directly detected (Dannenberg et al., 1990).

Online Journal of Art and Design
volume 15, issue 2, April 2027
DOI: https://doi.org/10.30935/ojad/2513147

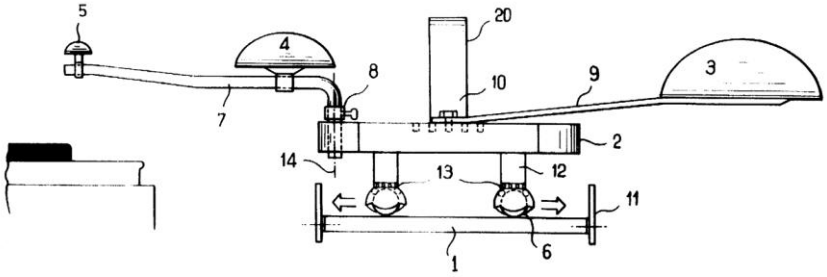


FIG.1

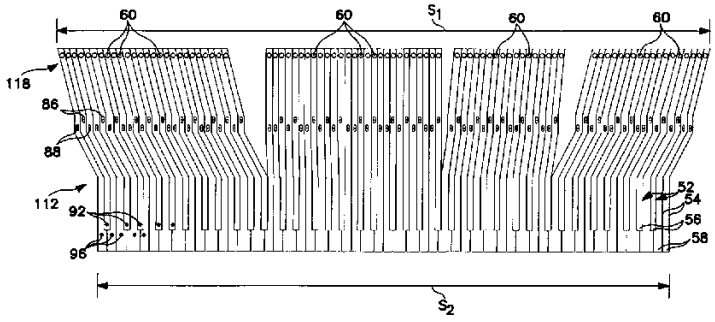


FIG. 2

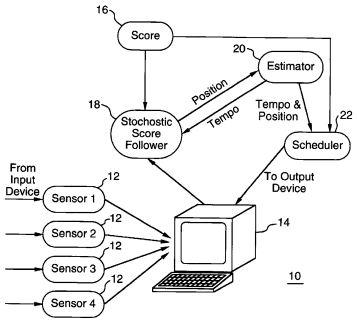


FIG. 1

The DS Standard specifies octave widths of 16.51 cm (DS6.5), 15.24 cm (DS6.0), and 14.06 cm (DS5.5) (DS Standard Foundation, n.d.).

Figure 7. Three sites of design intervention: (a) Saboia de Albuquerque's hand and forearm supports (Saboia de Albuquerque, 1998, US5753840A, Fig. 1; rotated excerpt); (b) Steinbuhler's reduced-size keyboard, showing the arrangement of keys (Steinbuhler, 2000, US6118063A, Fig. 2; rotated excerpt); (c) Grubb and Dannenberg's score-following system (Grubb & Dannenberg, 1999, US5913259, Fig. 1), a related technical illustration for the discussion of the Piano Tutor.

The defining transformation across this period was the increasing distinction between adapting the user to the product and adapting the product to the user. Mechanical guides maintained fixed technical norms, supports carried bodily load, alternatively sized keyboards altered the instrument, and computational systems transferred part of assessment to measurable indicators.

4.4. Analogue Continuity, Accessibility, and Data-Driven Systems: 2010–2026

After 2010, analogue resistance devices, normative hand-positioning aids, anthropometric adaptations, individually tailored accessibility systems, contactless movement tracking, and robotic apparatuses continued to coexist. The contemporary field is characterized not simply by digitalisation, but by the multiplication of modes of intervention.

Gripmaster, Varigrip, and FingerWeights are marketed for finger conditioning through pistons, springs, or added mass and are considered here as contextual comparisons. The resistance mechanisms alone do not reproduce piano-key response or demonstrate transfer to coordinated musical performance; FingerWeights may also be worn during playing. Responsibility for resistance, duration, repetition, and rest largely remains with the user (D'Addario, n.d.; FingerWeights, 2020; Prohands, n.d.). BubblHandz similarly continues the normative positioning approach in a lightweight, wearable form. The manufacturer provides size selection, strap adjustment, and gradual withdrawal instructions. Its emphasis on a correct hand arch nevertheless illustrates the persistence of a positional norm; its effect across different tasks is not established by those instructions (BubblHandz, n.d.).

Online Journal of Art and Design
volume 15, issue 2, April 2027
DOI: https://doi.org/10.30935/ojad/2513147

Accessibility-oriented systems adopt a different approach. The FEURICH pedal extension brings the pedals closer to the user, REMAP's individually tailored wrist support responds to a particular movement capacity, and Steingraeber systems remap pedal control from the foot to other available bodily movements (FEURICH, n.d.; REMAP, n.d.; Steingraeber & Söhne, n.d.). These products configure the pianist–instrument relationship by altering the instrument's control arrangement rather than requiring the body to conform to a fixed standard.

ROLI describes Airwave as using cameras and software to track hand movement and provide performance feedback. Although it removes material constraint, its feedback can be interpreted as locating technical norms within an algorithmic model. Field of view, tracking accuracy, latency, data privacy, and explainability consequently become relevant design and safety criteria (ROLI, n.d.).

Robotic systems extend assistance from assessing movement to generating or augmenting it. The Supernumerary Robotic Third Thumb expands hand reach through an additional robotic finger controlled by the user's foot, making control of a new movement possibility a primary criterion of success (Shafti et al., 2021). Furuya and colleagues' hand exoskeleton instead applied complex movement patterns passively to expert pianists' fingers. Its objective was not primarily to increase strength but to provide novel sensorimotor experience (Furuya et al., 2025). Unlike a commercial aid, however, the exoskeleton remains an experimental research prototype used under controlled conditions.

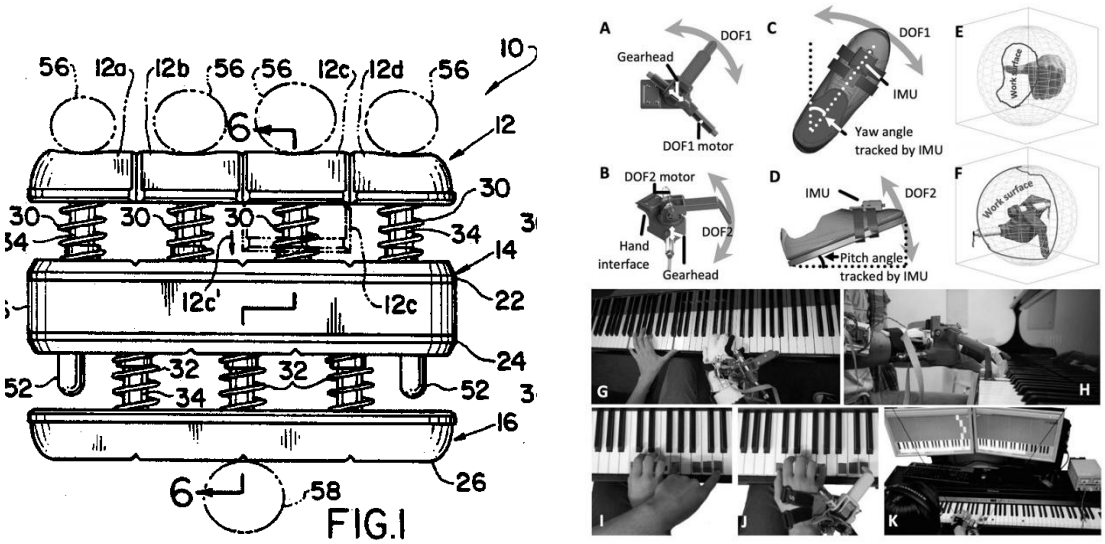


Figure 8. Two contrasting mechanical interventions: (a) Silagy's spring-plunger finger exerciser (Silagy, 1992, US5147256, Fig. 1), illustrating the mechanism discussed with Gripmaster; (b) Shafti et al.'s Supernumerary Robotic Third Thumb and piano tasks (2021, Fig. 1, https://doi.org/10.1038/s41598-021-00376-6), reproduced in grayscale under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

These products require different criteria of success. Mechanical load and safe dosage are central to resistance devices; independent access and user-specific control to accessibility systems; detection accuracy and data governance to camera-based systems; and alignment, control safety, and learning transfer to robotic prototypes. Commercial products, individually tailored aids, and research apparatuses should therefore remain analytically distinct.

Online Journal of Art and Design
volume 15, issue 2, April 2027
DOI: https://doi.org/10.30935/ojad/2513147

4.5. Cross-Period Synthesis: Transformations in the Pianist–Instrument Relationship

The historical corpus demonstrates that new technologies did not replace earlier design principles. Normative positioning, resistance, accessibility, computational feedback, and robotic movement support continue to coexist. Their transformation can be summarised across four related axes.

First, the site of intervention expanded from bodily position and capacity to instrument dimensions, keyboard layouts, control arrangements, instructional environments, and feedback systems. Second, models based on a common technical body were joined by ergonomic and accessibility-oriented approaches that treated bodily diversity as a design input. Third, feedback expanded from physical boundaries and resistance to mechanical cues, recorded movement, algorithmic interpretation, and generated movement. Fourth, pedagogical authority became distributed among method authors, teachers, product geometry, researchers, experimental protocols, software, designers, and users.

Table 1. Summary of the historical transformation of design approaches in piano-playing aids.

Design orientation	Predominant problem framing	Mode of intervention	Component through which fit is established	Principal evidential issue
Positioning	Incorrect hand and wrist position	Rail, frame, and physical boundary	User's body	Whether visible position demonstrates skill transfer
Resistance and conditioning	Insufficient strength, span, and independence	Springs, weights, and repeated loading	Physical capacity	Transfer of physical loading to piano performance
Measurement and feedback	Inability to observe movement	Clicks, graphs, photographs, and digital records	User, teacher, and assessment system	Whether measured variables represent integrated technique
Ergonomic adaptation	Dimensional mismatch between user and instrument	Supports, pedal extensions, and alternative keyboard layouts and sizes	Interface and instrument	Validity across different tasks and users
Computational tutoring	Limited error information during practice without a teacher	Performance detection and algorithmic interpretation	Software and feedback system	Difference between measurable outcomes and bodily movement
Accessibility	Barriers to sustained musical participation	Support and alternative control inputs	User–instrument access	User-specific participation, reliability, and continuing access
Robotic augmentation and sensorimotor training	Limits of existing movement or sensorimotor experience	Additional actuation or generated finger movement	Body–robot control system	Control safety, task-specific outcomes, and generalizability

Note. Rows describe design orientations, not exclusive product types or successive historical stages. A product can combine several orientations; the primary reporting categories and case identifiers are given in Table S1 in the Appendix.

The principal historical shift was an expansion from object-level intervention to relational and system-level design. Maintaining a prescribed hand position was joined by the regulation of physical load, movement measurement, anthropometric adaptation, alternative control channels, computational interpretation, and robotic movement generation. Greater technological complexity did not necessarily produce greater user autonomy. A simple support may provide more movement freedom than an advanced robotic system, while high-resolution tracking does not ensure the validity of pedagogical interpretation.

Counterexamples qualify this expansion. Chiroplast already combined an apparatus with organised teaching, and Jankó altered the interface in 1882; late wrist guides still prescribed bodily norms. Adjustable components also coexisted with normative technique, as Niks's (1992) patent illustrates. Commercial viability cannot be inferred from technical novelty: Kent's (1970) feasibility study distinguished technically possible computer-assisted instruction from economically feasible provision. Standardization, installation, and manufacturing costs therefore remain contextual constraints, rather than proven causes of every product's adoption or disappearance.

Product evaluation must therefore distinguish among technical function, safe use, intended change, and transfer to actual piano practice. Historical sources often treated these levels as equivalent, presenting a functioning mechanism as an effective teaching aid. The corpus instead supports comparison of where intervention is located and what evidence supports it. This shift has not eliminated normative conceptions of the body, but it has opened a broader design space in which the user, product, instrument, instructional system, and feedback environment may all be treated as open to change.

5. DISCUSSION AND DESIGN EVALUATION

The historical patterns identified above raise three interrelated questions for design evaluation: how pedagogical knowledge is materialized in products, how standardization and bodily diversity affect user autonomy, and how technical functions should be distinguished from claims about learning or health. These questions structure the following discussion and the proposed evaluation framework.

5.1. Materialised Pedagogy and Design Authority

Piano-teaching instructions such as "avoid dropping the wrist," "develop finger independence," "reduce unnecessary tension," and "transfer arm weight to the key" are context-dependent pedagogical propositions. When translated into products, they become decisions concerning dimensions, contact surfaces, resistance, movement boundaries, adjustability, and feedback. Design therefore not only materializes pedagogical knowledge but also reinterprets it by selecting which aspects of movement are considered significant. The same pedagogical objective may be addressed through interventions with different consequences. Wrist position, for example, may be regulated by a fixed rail, a movable support, or camera-generated feedback. A fixed rail physically restricts movement, a movable support carries physical load while permitting movement across the keyboard, and a camera system measures and interprets movement without preventing it. These approaches differ in both the freedom they afford and the intensity of guidance they provide. Technical objects also carry scripts that anticipate who the user is, how the user will act, and which decisions remain under user control (Akrich, 1992). The Chiroplast presupposed a student practising within boundaries established by the teacher and product geometry. Resistance devices assume users who regulate progress through load and repetition. Camera-based systems assume users who remain within the sensor's field of view, use compatible hardware, share movement data, and incorporate algorithmic recommendations into practice.

A product's pedagogical influence consequently extends beyond direct physical contact. Setup, practice sequence, repetition intervals, progress indicators, error messages, and decisions about when support should be withdrawn all regulate the user experience. Even a contactless system may structure practice through software, subscriptions, and feedback flows.

Piano-playing aids also extend instruction into periods when the teacher is absent. A fixed mechanism can reproduce the same intervention consistently, but cannot readily adjust it to repertoire, tempo, fatigue, or bodily difference. The continuity offered by the product may therefore introduce pedagogical rigidity.

Technological products influence perception, behavior, and decision-making rather than neutrally accompanying action (Verbeek, 2005). A resistance device may make spring stiffness a measure of progress, while a camera system may make movements highlighted on a screen the basis of technical assessment. Users may then evaluate progress through the variables the product makes visible.

This influence gives products authority over the body. Constraining products prevent movement, resistive products generate counterforce, supportive products carry bodily load, and augmentative technologies introduce new movement possibilities. Yet intervention intensity does not correspond directly to user autonomy. A lightweight aid may impose a strong norm by prescribing one correct hand form, whereas an individually tailored support may physically carry the arm while enabling a broader range of musical action.

Constraint is therefore not inherently negative. Temporarily reducing movement options may support elementary learning or establish a safe range of movement (Norman, 2013). Its purpose should nevertheless be explained, adapted to the user, and accompanied by a plan for reducing support. If appropriate movement occurs only while the aid is present, the product functions as a temporary performance apparatus rather than as a learning tool. Temporary pedagogical assistance must also be distinguished from continuous accessibility support. An instructional aid may be expected to transfer regulation gradually to the user. Continued use of an accessibility solution, however, does not indicate failure. Its value lies in enabling reliable, autonomous, and sustained musical participation.

5.2. Standardisation, Bodily Diversity, and User Autonomy

The piano is a largely standardized industrial product. Key width, octave span, keyboard height, and pedal position shape the pianist's physical relationship with the instrument. Although standardization benefits manufacturing, maintenance, education, and transfer between instruments, its prevalence does not establish ergonomic suitability for all users. Hand span, finger proportions, joint mobility, leg length, and strength vary considerably. Fixed dimensions may provide comfortable access for some users while requiring greater joint motion, muscular effort, or compensatory movement from others. Many historical aids treated this mismatch as a bodily deficiency and sought to prepare users for the standard piano. Alternatively sized keyboards, pedal extensions, and accessible control systems instead treated instrument dimensions and control arrangements as design variables.

Claims that reduced-size keyboards make playing easier assume standard key width to be an inherent condition of piano technique. Key width, however, is an interface characteristic rather than musical content. A narrower keyboard does not remove the demands of rhythm, articulation, dynamic control, coordination, or interpretation. It may reduce physical loading not integral to the musical task.

Keyboard size and hand span can affect muscular activity and finger position (Chi et al., 2021; Turner et al., 2026). These short-term biomechanical findings should not be interpreted as evidence of long-term injury prevention. Suitable keyboard dimensions also depend on finger proportions, repertoire, movement habits, user preference, and the need to transfer between instruments.

Design responses to bodily diversity can be organized at three levels:

- Add-ons preserve the standard instrument while addressing particular access difficulties through attached components, such as pedal extensions.
- Adaptations modify existing products according to user requirements, as in retrofitted keyboards or personalized supports.
- Redesign treats bodily diversity as an initial parameter of product architecture, for example by offering multiple keyboard sizes or alternative pedal-control inputs.

Inclusive design treats user diversity as an initial design input rather than a condition assessed after development (Clarkson et al., 2003). This does not require one product for

all users but an appropriate combination of shared features, adjustability, size options, and individually tailored solutions.

Accessibility also extends beyond physical operability. A personalised support or alternatively sized keyboard available only at home may not provide continuity across lessons, rehearsals, and performances. Physical, musical, and institutional access should therefore be considered together. Maintenance, repair, replaceable components, technical documentation, and service continuity are equally important, particularly when product failure can interrupt musical participation. In digital systems, software support, subscription conditions, data export, and compatibility following updates perform similar functions. Individual fit may also require specialist installation, replacement parts, or a compatible instrument at each institution. Affordability and shared access therefore need assessment alongside physical fit; the corpus does not provide comparable cost or maintenance data for all cases.

User autonomy does not require the absence of intervention. It requires users to understand the intervention, modify its settings, discontinue it when appropriate, and explore alternative movement strategies. Appearance, stage use, and personal identity may also influence whether a product supports meaningful participation (Pullin, 2009). Involving users in problem framing, prototyping, and evaluation strengthens design's capacity to respond to embodied knowledge and actual conditions of use (Sanders & Stappers, 2008).

5.3. Product Function, Learning, and the Limits of Evidence

A central difficulty in evaluating piano-playing aids is the distance between a product's technical operation and its claimed pedagogical outcomes. A spring generating resistance, a rail restricting movement, or a camera tracking joint position are verifiable functions. Improvements in finger independence, technical proficiency, practice efficiency, or injury prevention are separate research questions.

Product function, pedagogical interpretation, and marketing claim must therefore be distinguished. Resistance applied to the fingers is a physical function. The proposition that it develops finger capacity is a pedagogical interpretation. The claim that it improves piano playing requires evidence of skill transfer.

Four levels should be distinguished:

1. Technical function: Does the mechanism or computational system operate as intended?
2. Usability and safety: Can the user understand, adjust, and safely operate it?
3. Intended outcome: Does the proposed physical, cognitive, or technical change occur?
4. Skill transfer: Is the change retained without the product and across different piano tasks?

Immediate performance with a product is not equivalent to learning. An apparatus may maintain wrist height, but learning requires the movement pattern to be retained after its removal. Transfer further requires the capability to be applied across different passages, tempi, dynamics, and instruments.

Off-piano resistance devices may exclude auditory outcomes, key movement, lateral movement across the keyboard, and coordination between fingers and wrist. Transfer to piano performance therefore depends on task similarity and learning conditions (Müssgens & Ullén, 2015). Temporary instructional aids should be evaluated through delayed tests and unaided performance. Accessibility products require a different criterion: the product need not be removed if it enables independent and sustainable musical participation.

Commercial descriptions and research findings also have different evidential status. Manufacturer documentation may establish mechanism, intended use, and marketing

claims, but does not demonstrate independent effectiveness. A successful individually tailored case may provide strong evidence for one user without being broadly generalizable. Similarly, an experimental prototype does not necessarily constitute a safe, manufacturable product suitable for everyday use. For historical products, an undocumented safety provision is not evidence of either safety or harm. Proposed force limits, stop controls, or maintenance checks below are evaluation requirements, unless explicitly identified as documented features.

Short-term biomechanical changes should not be translated directly into health claims. Lower muscular activity or a more neutral joint position may be ergonomically meaningful without demonstrating long-term injury prevention. Existing reviews show substantial differences among studies in their tasks, samples, and methods (Bragge et al., 2006; Chi et al., 2020).

In computational products, measurement and pedagogical interpretation may be combined within a single notification. "The wrist is at this height" is descriptive, whereas "the wrist is at the wrong height" is normative. Applying one reference movement across users and tasks may obscure the context-dependent diversity of piano movement.

Algorithmic feedback depends on a chain of sensor, data model, classification rule, and interface. Each component determines what can be detected, how the body is represented, which thresholds define correct technique, and how users interpret the result. Measurement error should not be presented as user error. Low-confidence estimates should be identified, detection limits explained, and user correction supported (Amershi et al., 2019). Trust should remain proportionate to the system's actual capabilities (Parasuraman & Riley, 1997).

Feedback timing also matters. Continuous real-time notifications may redirect attention from sound and musical expression towards the screen. Systems should allow feedback during movement, after a passage, or at the end of a session according to the user's experience and practice objective. Data processing, deletion, offline operation, and post-subscription functionality should also be transparent. Algorithmic personalization may increase control while creating new dependencies through collecting bodily and behavioral data.

5.4. An Evaluation Framework for Industrial Design

Piano-playing aids cannot be assessed through a single criterion of success. Force limits and emergency stopping are critical in a powered exoskeleton, while slippage and movement transfer are central to a pedal extension. A camera-based system raises questions of detection accuracy, latency, explainability, and data use. The following framework is therefore intended not to rank products, but to evaluate problem framing, user interaction, learning objectives, evidence, and continuity of use together. Problem, user, intervention, control, and claim–evidence correspondence are core questions. Learning transfer is central to training devices; continued participation to accessibility systems; sensing accuracy and privacy to data-processing systems; and powered-motion safeguards to actuated devices.

Table 2. Qualitative industrial design evaluation framework for piano-playing aids.

Dimension	Principal question	Data to be examined
Problem and user	Which user, task, and mismatch are defined?	Task analysis, user accounts, anthropometric distribution
Site of intervention	Is change directed towards the body, interface, instrument, environment, or information flow?	Contact points, mechanism, system relationships
Operating principle	How does the product influence behaviour?	Constraint, resistance, support, measurement, feedback, actuation
Bodily fit	Are force, movement range, and contact appropriate for the user?	Contact pressure, joint alignment, load, repetition, fatigue

Adjustment and user control	Can the user understand, modify, and discontinue the intervention?	Adjustment range, control visibility, error and safe-stop scenarios
Feedback	Can measurement be distinguished from pedagogical interpretation?	Accuracy, latency, uncertainty, explainability
Learning and transfer	Is the outcome retained without the product and across different tasks?	Delayed tests, unaided performance, varied repertoire
Claim and evidence	What evidence supports the claimed benefit?	Technical testing, usability studies, independent experiments, long-term monitoring
Access and participation	Can the user sustain the intended musical activity?	Real-world use, user preference, institutional access
Lifecycle	Can the product remain usable over time?	Installation, maintenance, repair, servicing, software, replacement parts
Ethics and privacy	How are bodily or digital data collected and used?	Consent, data ownership, storage, sharing, deletion

Applying the framework should begin with the musical task the user finds difficult, rather than a predetermined product idea. Before framing difficulty as a bodily deficiency, the roles of the task, interface, instrument, and environment should be examined. Pedagogical measures, interface adaptation, environmental adjustment, and direct bodily intervention can then be compared.

Intervention intensity should be proportionate to need. High resistance, movement constraint, or powered guidance should not be the first response when a simpler interface or environmental adjustment is sufficient. Stronger control over bodily movement requires correspondingly stronger evidence of safety and effectiveness.

The relevant lifecycle also depends on product purpose. Pedagogical products may progress from initial assessment to supported practice, reduced support, and transfer to unaided performance. Accessibility products instead prioritize reliability, maintenance, and continuity across environments. Digital systems additionally require software support, data portability, and compatibility after updates.

The framework should not generate a single aggregate score because safety, learning transfer, accessibility, and aesthetic preference are not interchangeable. Critical dimensions should be selected according to product status and purpose, while gaps in evidence remain visible.

Each criterion should be recorded as applicable with supporting evidence, not applicable (with a reason), not documented in the sources examined, conflicting evidence, or evaluated and found unsatisfactory. "Not documented" does not mean that no evidence survives anywhere, and must not be scored as failure. Table 3 applies the framework to Chiroplast, a REMAP support, and ROLI Airwave. The examples distinguish potential strengths from untested benefits and identify evaluation priorities; they demonstrate use of the framework, not its empirical validity.

Table 3. Worked application of the evaluation framework to Chiroplast, REMAP piano wrist supports, and ROLI Airwave.

Criterion	C01 Chiroplast	C30 REMAP support	C32 ROLI Airwave
Purpose and user	Learning positional technique; temporary training support.	Continued playing with individual support; aid withdrawal is not the goal.	Feedback during learning within a compatible digital ecosystem.
Documented basis	Rails/guides and instructional system (Logier, 1816; Taylor, 1900a; Rainbow, 1990).	Built rails and pivoting supports; provider reports resumed playing (REMAP, n.d.).	Manufacturer describes camera tracking and app-based feedback (ROLI, n.d.).
Potential design strength Interpretation	Repeatable positional guidance; teaching proposition is visible in geometry.	Support can enable lateral movement while carrying load.	Contactless observation may reveal movement without a mechanical barrier.

Control and bodily diversity	Guide adjustment exists; conformity to keyboard-based divisions remains. User experience not documented.	Tailored to one user; broader suitability not established.	Compatibility is specified; appropriateness of normative feedback across bodies/tasks remains open.
Learning or participation evidence	Retained unaided learning: not documented in the sources examined.	Single provider-reported participation outcome; independent longitudinal evidence not documented.	Retained learning and cross-repertoire transfer: not demonstrated by manufacturer description.
Not applicable	Digital-data privacy, provided no data system is added.	Unaided transfer as a necessary success criterion for continuing accessibility support.	Powered finger-motion safeguards; the learning system does not impose finger motion.
Safety and lifecycle priorities	Assess contact/constraint and task compatibility; absent records do not establish harm.	Assess support fit, mounting, wear and continued 47ccess.	Assess tracking error, feedback comprehension, data control and software continuity.
Evaluation priority	Delayed unaided performance across tasks; preserve historical/experimental distinction.	User-defined participation over time and across settings.	Independent validation of measurement and learning outcomes.

Note. These documentary examples demonstrate use of the framework, not its empirical validation. Documented features, provider claims, and design interpretations are distinguished; evaluation priorities are proposals for subsequent investigation. Case identifiers refer to Tables S1 and S2 in the Appendix. No comparable test of the three products is claimed.

The design value of a piano-playing aid lies not in technological complexity but in the meaningful possibilities it creates for movement, learning, and participation. Configuring the pianist–instrument relationship prevents the requirement for change from being assigned automatically to the body. The user, interface, instrument, teaching method, practice environment, and feedback system may all be treated as designable components.

6. CONCLUSION AND RECOMMENDATIONS FOR INDUSTRIAL DESIGN RESEARCH

This study shows how piano-playing aids materialized pedagogical knowledge, redistributed responsibility for pianist–instrument fit, and shifted design intervention across the body, instrument, interface, and feedback system. The corpus reveals not a linear progression from mechanical to digital technology, but the continuing coexistence of normative guidance, physical conditioning, ergonomic adaptation, accessibility, computational assessment, and robotic augmentation.

6.1. Principal Findings and Contributions to Design Research

The study's first contribution is to identify piano-playing aids as instances of materialized pedagogy. Teaching propositions concerning wrist position, finger independence, arm weight, or hand form were translated into product geometry, contact surfaces, resistance levels, keyboard dimensions, and feedback rules. In this translation, pedagogical knowledge was not merely represented but reinterpreted according to the variables products could constrain, support, measure, or classify.

These features embody particular models of the body and user. Early guides treated the hand and wrist as structures expected to conform to predefined positions. Resistance devices associated technical development with strength and endurance, while measurement apparatuses transformed movement into observable data. Ergonomic and accessibility-oriented products shifted the problem towards instrument dimensions and control arrangements, treating mismatch as relational rather than exclusively bodily.

The second contribution is a comparison based on the site of intervention. Piano-playing aids may constrain the body, apply resistance, support physical load, alter instrument dimensions, record movement, or introduce new movement capacities. Even when directed

towards similar pedagogical objectives, these interventions have different implications for safety, user autonomy, and skill transfer.

The third contribution is to make design and pedagogical authority explicit subjects of evaluation. Products define not only how movement is supported, but also which movements are appropriate, which variables are monitored, and how progress is interpreted. In mechanical aids, this authority is embodied in product geometry. In computational systems, it is distributed across sensing, classification, and feedback. Removing physical constraint therefore does not eliminate normative guidance. It may instead relocate the norm within an algorithmic assessment model.

User autonomy should consequently be understood not as the absence of intervention, but as the extent to which intervention is comprehensible, adjustable, interruptible, and reversible. Continued use of an accessibility product should likewise not be treated as dependency when it expands the user's capacity for musical decision-making and participation.

The final contribution is the distinction among technical function, pedagogical claim, and scientific evidence. A working resistance mechanism or movement-tracking camera performs a verifiable technical function. Retained learning, transfer across repertoire, or injury prevention require separate evidence. Immediate improvement with a product is not equivalent to learning or skill transfer.

6.2. Design Principles for Contemporary Piano-Playing Aids

The historical analysis supports three overarching principles for designing contemporary piano-playing aids.

Relational Problem Framing: Technical difficulty should not automatically be framed as a deficiency of the user's body. Hand span, pedal 48ccess, movement control, and fatigue should be examined in relation to instrument dimensions, task demands, seating, practice duration, and feedback. Design should begin with the musical task and the conditions under which a particular user experiences difficulty.

The lowest effective level of intervention should then be considered. High resistance, physical constraint, or powered guidance should not be the first response when pedagogical strategy, interface adaptation, or environmental adjustment can provide adequate support. Increasing control over bodily movement requires correspondingly stronger evidence of safety and effectiveness.

User Autonomy: Adjustability should be accompanied by meaningful user control. Users should understand the purpose and implications of settings, recognize inappropriate adjustment, return to a safe configuration, and discontinue the intervention when necessary. Powered systems require force limits and emergency stopping, while digital systems should allow users to disable feedback, reject algorithmic recommendations, and delete their data.

Temporary instructional support should also be distinguished from continuous accessibility support. Instructional products success to reduce external guidance and support transfer to unaided performance. Accessibility products instead succeed by enabling reliable and sustained musical participation. Their design must therefore include maintenance, repair, compatibility across instruments, and continuity of technical service.

Evidence-Aligned Product Claims: Product communication should distinguish technical function, immediate physical change, learning, skill transfer, and long-term health outcomes. A functioning mechanism does not establish pedagogical effectiveness; usability does not demonstrate retained learning; and short-term biomechanical change does not establish injury prevention.

Computational feedback should similarly distinguish observation from interpretation. "The wrist is at this height" describes a measurement, whereas "the wrist is at the wrong height" expresses a pedagogical judgement. Systems should communicate measurement uncertainty, explain the basis of assessment, and allow users to correct or reconfigure feedback for different pedagogical objectives.

The entire product lifecycle should also be considered. Analogue products require attention to wear, cleaning, replacement parts, installation, and compatibility. Digital products additionally require software support, data ownership, offline use, subscription continuity, and compatibility following updates.

6.3. Limitations and Future Research

The corpus is not a complete inventory of piano-playing aids. Some products are documented only through patents, advertisements, or secondary accounts. These sources may establish design intent, commercial presentation, or physical existence, but none independently demonstrates widespread use or pedagogical effectiveness. Archival preservation, language, institutional collecting, and digitization may also have made some products more visible than others. The sources are geographically concentrated in Europe, North America, and Japan and unevenly accessible across languages. Patented, advertised, digitized, and institutionally collected objects are more visible than informal, locally made, short-lived, or unsuccessful aids. The historical patterns therefore describe this documented selection and cannot establish global prevalence or the frequency of each design strategy.

The proposed evaluation framework is a conceptual tool derived from historical comparison and 49ccess4949re synthesis. It has not been validated as a standardized measurement or scoring system. Future research should examine its applicability across product categories, its consistency among specialists and users, and its integration into design processes.

The historical corpus could be expanded through commercial catalogues, conservatoire records, teachers' documents, user correspondence, and local music publications. These materials may clarify differences among patented design intent, actual production, commercial distribution, and use. Historical products with sufficient documentation could also be reconstructed physically or digitally to examine the movement possibilities enabled or constrained by their geometry, without treating their pedagogical claims as established facts.

Alternatively sized keyboards and accessibility systems require longitudinal research in real-world contexts. Future studies should consider adaptation time, repertorial transfer, musical expression, user preference, maintenance, and institutional success alongside short-term biomechanical measurements.

Artificial intelligence-supported tutoring systems should be examined independently in terms of the movement models they treat as normative, the users represented in their training data, the effects of inaccurate feedback, and the distribution of decisions between teacher and software. Movement-data governance and users' interpretations of algorithmic recommendations also require attention.

Finally, future product development should involve pianists, students, teachers, piano technicians, healthcare professionals, and accessibility specialists from the early design stages. Co-design should encompass problem framing, priorities, prototyping decisions, and criteria of success rather than being limited to final-stage usability evaluation (Sanders & Stappers, 2008).

The history of piano-playing aids should not be interpreted as liberation from bodily control. What changed was the site of control: mechanical rails, resistance mechanisms, keyboard dimensions, accessible interfaces, or algorithmic assessment models. From an industrial design perspective, the objective is therefore not greater intervention but determining which intervention is appropriate for a particular user and musical task, how long it should remain active, and what evidence supports it. A successful piano-playing aid does not seek to eliminate bodily difference. It configures the relationship among body, instrument, and musical purpose while preserving the user's scope for decision-making and keeping its claims within available evidence.

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APPENDIX

A configuration may be an individual product, an integrated system, or a related family. The inventory contains 34 configurations: 30 piano-specific configurations and four contextual/boundary comparisons (C17 and C25–C27). Related patents are not counted as separate products unless the design configuration differs. The Hand Guide family includes its associated silent practice keyboard; children's aids and Ortmann's apparatuses remain grouped as in the article. Dates distinguish a design, patent publication, surviving object or source date; "undated" never supplies an invention date.

Each configuration is assigned one primary reporting category to avoid double counting; mechanisms and purposes may overlap. Narrative sections retain their original, partly overlapping period headings. A contemporary appearance in Section 4.4 is not evidence of invention after 2010. Source types below distinguish patented proposal, preserved object, advertisement, manufacturer description, institutional use and research. Developer-led experiments are research evidence but are not automatically independent evaluations. The primary categories comprise conditioning (10), positioning (7), interface adaptation (4), instructional systems (4), accessibility support (4), measurement and awareness (2), robotics (2), and silent practice (1).

Table S1. Corpus inventory and documentary status

Full bibliographic entries are in the reference list. NMAH denotes the National Museum of American History. An institutional record establishes the particular documented object, not the quantity produced. Advertisement and manufacturer statements establish presentation or offering, not prevalence or independently verified benefit. Undocumented attributes are left open rather than reconstructed from product names.

Table S1. Corpus inventory and documentary status

ID and configuration	Date and narrative location	Category	Documentary source	Documented status
C01 Chiroplast	1814; French drawing 1819 Section 4.1	Positioning	Logier (1816); Taylor (1900a); Rainbow (1990); INPI (1819), dossier 1BA1265.	Apparatus and instructional system documented; prevalence not quantified.
C02 Kalkbrenner Hand Guide family	Nineteenth century; undated French edition and 1832 Leipzig edition Section 4.1	Positioning	Kalkbrenner (n.d.), BnF FRBNF43070565; Saint-Saëns (1919). Kalkbrenner (1832, p. 28), Figure 2.	Method and apparatus illustrations; associated silent keyboard grouped here.
C03 Dactylion	Ca. 1836 Section 4.1	Conditioning	Herz (1836), BnF FRBNF43048906; Musée de la musique (n.d.-b), E.980.6.2.	Method and preserved object.
C04 Assouplisseur de doigts	Ca. 1845–1846 Section 4.1	Conditioning	Levacher d'Urclé (1846); Musée de la musique (n.d.-a), record 0161511.	Treatise and museum record.
C05 Digitorium	1866 patent; object dated 1860–1880 Section 4.1	Conditioning	Taylor (1900b); Powerhouse (n.d.), 2001/12/1; "Digitorium Advertisements" (1869).	Preserved object and advertisement; production distinguished from patent.
C06 Jankó keyboard	1882 design; object ca. 1888–1892 Section 4.2	Interface adaptation	National Museum of American History (n.d.-a), MI.299840; nmah_605857.	Manufactured Decker Brothers piano; record describes limited historical continuity.
C07 Technicon	1885; advertisement 1897 Section 4.2	Conditioning	Brotherhood (1885), US327918A; NMAH (n.d.-b), MI.66.144; 1897 advertisement.	Patent, object and commercial offering; sales 55ccess unknown.

C08 Virgil Practice Clavier	1886 patent; 1895 method; object ca. 1896 Section 4.2	Silent practice	Virgil (1886), US344462A; Virgil (1895); NMAH (n.d.-c), 1983.0485.01.	Patent, method and manufactured object.
C09 Ortmann research apparatus family	1925–1929 publications Section 4.2	Measurement and awareness	Ortmann (1925, 1929).	Laboratory apparatuses and published research; not a single retail product.
C10 Magic Finger Developer	February and March 1938 advertisements; also 1948 spread Section 4.3	Conditioning	"Magic Finger Exerciser" (1938a, 1938b); "Jenkins Children's Piano Aids" (1948). 1938 advertisement pages: 113 and 183.	Advertised device; separate advertisements verified in the February and March 1938 issues.
C11 Children's piano aids family	1948 advertisement Section 4.3	Interface adaptation	"Jenkins Children's Piano Aids" (1948), pp. 48–49. Sappenfield (1936), US2047332A, is a related patent illustration in Figure 6b.	Advertised music rack, footrest/pedal control and junior pedals.
C12 Wurlitzer Music Laboratory	Documented in 1970; related patent filed 1969, granted 1971 Section 4.3	Instructional systems	Kent (1970), ERIC ED038039. Andersen (1971), US3584530A, Figure 6c.	Institutional report and patent documentation; extent of classroom uptake not established.
C13 Harrington playing aid	1980 patent publication Section 4.3	Positioning	Harrington (1980), US4204455A.	Patent proposal; manufacture/adoption not established.
C14 Mikimoto Finger-Board	1980 patent reported in 2009 thesis Section 4.3	Measurement and awareness	Hosaka (2009), University of Maryland dissertation.	Pedagogical account; original Japanese patent identifier not verified.
C15 Bonasera finger exerciser	1988 patent publication Section 4.3	Conditioning	Bonasera (1988), US4765608A. Patent drawing reproduced in Figure 6a.	Patent proposal; production and adoption unestablished.
C16 Niks hand and wrist exerciser	1989 patent publication Section 4.3	Conditioning	Niks (1989), US4836531A.	Patent proposal; use/health claims remain inventor statements.
C17 Yamaha HS-500	1982 product Section 4.3	Instructional systems	Yamaha Corporation (n.d.), Innovation Road item 2040.	Commercial keyboard; boundary comparison, not a piano attachment.
C18 Niks piano exercising device	1992 patent publication Section 4.3	Positioning	Niks (1992), US5082258A.	Patent; reported trials are inventor claims, not independently inspected reports.
C19 Iwatani wrist guide	1995 patent publication Section 4.3	Positioning	Iwatani (1995), JPH0792898A.	Japanese patent publication; translated description.
C20 Michelson–Maurer wrist trainer	2007 patent grant Section 4.3	Positioning	Michelson & Maurer (2007), US7169086B2.	Patent; grant date differs from 2006 application publication.
C21 Saboia de Albuquerque support family	1993 A1; 1994 B1; 1998 US grant Section 4.3	Accessibility support	Saboia de Albuquerque (1993, 1994, 1998): FR2685803A1/B1; US5753840A.	Related patent records grouped as one configuration family.
C22 Sato auxiliary appliance	2000 patent publication Section 4.3	Accessibility support	Sato (2000), JP2000137483A.	Patent proposal, not proof of an adopted product.
C23 DS Standard keyboard family	Development before 2010; studies 2021/2026 Section 4.3	Interface adaptation	DS Standard Foundation (n.d.); Chi et al. (2021); Turner et al. (2026). Steinbuhler	Manufactured size system; biomechanical studies separately identified.

			(2000), US6118063A, Figure 7b.	
C24 Carnegie Mellon Piano Tutor	1990 publication Section 4.3	Instructional systems	Dannenberg et al. (1990). Grubb and Dannenberg (1999), US5913259, is a related score-following illustration in Figure 7c.	Research tutoring system; general commercial adoption not established.
C25 Gripmaster	Undated contemporary documentation Section 4.4	Conditioning	Prohands (n.d.), FAQs. Silagy (1992), US5147256, illustrates the spring-plunger mechanism in Figure 8a.	Commercial general-purpose device; contextual comparator. The patent illustrates a mechanism, not a specific marketed model.
C26 Varigrip	Undated contemporary documentation Section 4.4	Conditioning	D'Addario (n.d.), Varigrip hand exerciser.	Commercial general-purpose device; contextual comparator.
C27 FingerWeights	2020 manufacturer article Section 4.4	Conditioning	FingerWeights (2020).	Commercial general-purpose device; contextual comparator.
C28 BubblHandz	Undated contemporary instructions Section 4.4	Positioning	BubblHandz (n.d.), Getting started.	Marketed pedagogical aid; manufacturer evidence.
C29 FEURICH pedal extension	Undated contemporary documentation Section 4.4	Interface adaptation	FEURICH (n.d.), Pedal extensions.	Manufacturer-described commercial accessory.
C30 REMAP piano wrist supports	Documented by 2024; exact completion date unspecified Section 4.4	Accessibility support	REMAP (n.d.), Piano wrist supports, project SO2-24.	Built individual solution; provider-reported use.
C31 Steingraeber pedal systems	Undated contemporary documentation Section 4.4	Accessibility support	Steingraeber & Söhne (n.d.).	Manufacturer-described configurable systems.
C32 ROLI Airwave	Contemporary system; source undated Section 4.4	Instructional systems	ROLI (n.d.), Airwave for learners.	Commercial system described by manufacturer.
C33 Supernumerary Robotic Third Thumb	2021 study Section 4.4	Robotics	Shafti et al. (2021), doi:10.1038/s41598-021-00376-6.	Research prototype and developer-led experiment.
C34 Hand exoskeleton	2025 study Section 4.4	Robotics	Furuya et al. (2025), doi:10.1126/scirobotics.adn3802.	Research apparatus and developer-led experiment.

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Table S2. Case by case analytical matrix

User and objective identify the intended body and task. Mechanism includes bodily contact, instrument attachment and documented construction. Control includes adjustment, user/teacher decisions and release where known. The final column separates the intended outcome from supporting evidence and unresolved information. Missing material, dimensions, maintenance or production details remain not documented unless specified in S1 or S2; omission is not proof that a feature did not exist.

Table S2. Case by case analytical matrix

Case	Intended user and objective	Mechanism and construction	Adjustment and control	Transfer evidence and uncertainty
C01 Chiroplast	Students; guide hand and finger position.	Keyboard-mounted rails and finger divisions; wood/brass described by Taylor.	Sliding guides and regulating screws; teacher sets boundaries.	Transfer to unaided playing assumed, not demonstrated by these sources; actual user responses unknown.
C02 Kalkbrenner Hand Guide family	Students; organise forearm position and practice.	Horizontal support at the keyboard; finger channels removed.	Support position adjustable in the method; user retains finger motion.	Repertoire compatibility is disputed in historical commentary; no controlled transfer test.
C03 Dactylion	Piano students; claimed finger independence and strength.	Finger rings linked to springs; resistance during key movement.	Exercise sequence prescribed; individual load calibration not established.	Pedagogical benefit is a method claim; retained learning, dosage and safety outcomes not documented.
C04 Assouplisseur de doigts	Instrumentalists; increase finger span and flexibility.	Mechanical finger-spacing/stretching intervention away from piano.	Adjustment range and release procedure not established in the submitted account.	Stretching-to-performance transfer assumed; user outcomes and tolerable forces not documented.
C05 Digitorium	Amateur players; claimed strength and evenness.	Five resistant keys in timber/ivory/metal box; 69 × 162 × 210 mm.	Portable; loading characteristics vary by version.	Resistance differs from piano touch; advertised improvement is not transfer evidence. Maintenance history unknown.
C06 Jankó keyboard	Pianists; change spatial and fingering relationships.	Multi-row key layout; integrated instrument interface.	Player learns alternative fingering; geometry not adjusted during use.	Relearning/compatibility issues documented in museum account; no general comparative learning result.
C07 Technicon	Students/teachers; train fingers, wrist and forearm.	Springs, rings, levers and weights; wood/metal/fabric apparatus.	Several loading arrangements; teacher/student models.	No common dosage standard or retained-skill evidence; differentiated models show market positioning.
C08 Virgil Practice Clavier	Students; practise action and timing without piano tone.	Resistant keyboard and clicks; preserved model has folding stand.	Resistance adjustable; up-click operating restriction recorded on object.	Clicks supply timing cues, not musical tone; long-term transfer and injury outcomes unestablished.
C09 Ortmann research apparatus family	Researchers/pianists; examine movement and force.	Pantographs, mechanical links, recording surfaces and photography.	Researcher selects recorded plane, task and setup.	Observations depend on apparatus/protocol; teaching transfer not a demonstrated product outcome.

C10 Magic Finger Developer	Players; claimed improvement in finger action.	Wearable arm-to-finger elastic resistance.	Strap placement and elastic length/tension govern intervention.	Advertising claims only; original designer, calibrated load and durable learning unresolved.
C11 Children's piano aids family	Children; reach adult-sized instrument contact points.	Raised foot support, pedal extensions and adjustable music rack.	Height/placement settings vary by component.	Sustained 59ccess is relevant; no evidence that support removal is required. Fit and durability not tested here.
C12 Wurlitzer Music Laboratory	Teacher and student groups; organise listening and instruction.	Teacher console, student keyboards, headphones/microphones and channel routing.	Teacher selects individuals/groups; users play their own stations.	Communication capacity does not measure bodily technique; installation, cost and maintenance affect provision.
C13 Harrington playing aid	Beginning keyboard players; maintain selected finger intervals.	Rigid wearable grip/bridge; patent proposes moulded construction.	Predefined geometry; sizing is not unrestricted movement control.	Intended correct interval is an inventor claim; retention, comfort and repertoire fit untested here.
C14 Mikimoto Finger-Board	Students; develop contact and tension awareness.	Off-piano tactile board with individually positioned contact surfaces.	Geometry partly personalised; teacher/user interpret bodily sensation.	Pedagogical description is not independent efficacy evidence; transfer and material specifications incomplete.
C15 Bonasera finger exerciser	Musicians including keyboard users; resist finger movement.	Wrist-mounted fork/bar and elastic finger links; lightweight metal proposed.	Screw and strap positions adjustable; no measured safe dosage.	Inventor's intended gains do not demonstrate retention or health benefit.
C16 Niks hand and wrist exerciser	Piano players; coordinate wrist and finger exercise.	Elbow stop, spring-loaded sliding/hinged hand rest and accessory keys.	Configured mechanical axes; fit and spring settings constrain movement.	Piano-conditioning transfer claimed; independent outcome evidence not established in the corpus.
C17 Yamaha HS-500	Children; ear-training games.	Portable 25-key electronic keyboard with auditory response.	User chooses/plays games; system determines task feedback.	Pitch/chord recognition differs from bodily piano technique; motor-transfer evidence not identified.
C18 Niks piano exercising device	Students/pianists; guide wrist and finger coordination.	Keyboard-length bar and finger guides.	Bar height, reach and guide positions adjustable to player/instrument.	Adjustment coexists with prescribed technique; retained learning and safety not independently established.
C19 Iwatani wrist guide	Keyboard students; prevent low wrist position.	Bar supported by brackets attached at keyboard sides.	Height and distance adjustable; contact occurs below intended position.	Corrective effect is proposed; independent learning, manufacture and adoption evidence lacking.
C20 Michelson–Maurer wrist trainer	Piano students; prompt wrist/forearm position.	Rod and supports create physical boundary near keyboard.	Setup controls location; user movement remains norm-referenced.	Pedagogical transfer, user diversity and market adoption not established by patent.
C21 Saboia de Albuquerque support family	Keyboard users; carry arm/hand load while permitting motion.	Sliding and rotating anatomical rests supported near the keyboard.	Support follows movement; adjustable positioning described in patents.	Sustained supported playing is relevant; independent user outcomes and commercial adoption unestablished.
C22 Sato	Users with limited arm support	Forearm support surface mounted in	Mounting configuration	Participation while supported is relevant;

auxiliary appliance	capacity; enable keyboard 60ccess.	front of keyboard; protective contact materials proposed.	determines support; tested adjustment range unknown.	comfort, fit and long-term use not independently established.
C23 DS Standard keyboard family	Pianists with different hand spans; reduce dimensional mismatch.	Alternative octave/key widths; instrument action/interface adapted.	User chooses size; availability limits choice across venues.	Task-specific biomechanics do not prove injury prevention; adaptation/transfer and institutional 60ccess require assessment.
C24 Carnegie Mellon Piano Tutor	Beginners; feedback during practice between lessons.	Performance sensing, expert system and multimedia instruction.	Software selects feedback/lessons; teacher remains part of learning context.	Measured performance errors differ from bodily technique; broad long-term transfer not established here.
C25 Gripmaster	Musicians/general users; claimed strength and endurance.	Portable independent spring pistons held in the hand.	Dedicated resistance models rather than continuously adjustable resistance.	Musician marketing does not establish piano adoption or skill transfer; instructions include stopping for pain.
C26 Varigrip	Musicians/general users; finger conditioning.	Portable spring-loaded pistons; product documentation also targets guitar use.	Resistance adjustable per finger.	Piano-specific adoption and transfer not established by cited manufacturer documentation.
C27 FingerWeights	Musicians; claimed endurance and finger control.	Wearable added mass; may be worn during instrument playing.	Removable loading rods; user controls session and removal.	Injury-prevention and performance statements are manufacturer claims; piano-specific learning evidence absent here.
C28 BubblHandz	Piano learners; tactile cue for hand arch.	Palm-contact form secured by wrist strap; wearable.	Sizes, strap adjustment and gradual withdrawal instructions provided.	Unaided 60ccess60 checks are advised, not independent transfer results; suitability across musical tasks uncertain.
C29 FEURICH pedal extension	Children; reach pedals on adult-sized instruments.	Mechanical extension of pedal contact point.	Manufacturer states compatibility with several instrument types; exact fit must be checked.	Continued 60ccess, mounting stability and pedal expression matter; learning benefit not independently demonstrated here.
C30 REMAP piano wrist supports	One user with reduced arm capacity; resume playing.	Aluminium rails, rollers and printed pivoting wrist rests.	Tailored supports; lateral movement and removal provision described.	Provider reports restored playing; no independent longitudinal comparison or population-level effect.
C31 Steingraeber pedal systems	Wheelchair users; operate pedals through available movement.	Switches/sensors linked to solenoids or actuators; alternative bodily inputs.	Input mapping tailored to user; some options allow intermediate pedal levels.	Sustained expression and reliability matter; configurations have differing installation and service requirements.
C32 ROLI Airwave	Learners; hand-tracking feedback.	Camera/software linked to compatible ROLI keyboard and learning app.	User configures ecosystem; scope for overriding judgements requires evaluation.	Tracking specifications and learning claims are not independent retained-learning evidence; compatibility and data controls matter.

C33 Supernumerary Robotic Third Thumb	Experienced/naïve players; explore augmentation control.	Wearable extra robotic digit controlled through the foot.	User coordinates hand and foot; prototype-specific setup.	Task-specific augmented playing studied; not unaided learning, routine accessibility provision or general safety validation.
C34 Hand exoskeleton	Expert pianists; novel sensorimotor experience.	Powered independent finger movements during passive exposure.	Protocol sets imposed motion; safeguards require device-specific documentation.	Task-specific post-exposure gains reported; not general pedagogy, long-term injury prevention or commercial suitability.