RESEARCH ARTICLE

Universal design for integrated wellness and fitness equipment

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The advancement of universal design in China has trailed global standards, resulting in a divergence in access. With the increasing elderly population in China, the necessity for universal design has gained enhanced importance. This study centered on pioneering research to create a versatile wellness and fitness apparatus that integrated leisure and rehabilitation with a specific focus on vulnerable groups such as the elderly and disabled individuals. Through an analysis of ergonomic workstation chair designs and the psychological influence of colors, this study integrated functional design elements into the product. The resulting device adhered to ergonomic standards was user-friendly and encompassed adaptable tabletops and swiveling chairs to ensure effortless accessibility. It appealed to a diverse demographic, notably emphasizing access for special needs populations, thereby introducing novel variations to the wellness manufacturing domain. The resulting product had noteworthy academic, practical, and commercial values.

Keywords: universal design; ergonomics; workstation chair; color psychology.

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Introduction

The concept of universal design is founded on humanization, aiming to accommodate individuals with disabilities and those facing mobility challenges [1]. In 1974, the United Nations (UN) introduced the term “Universal Design”, which has since evolved into a leading international design paradigm [2]. The UN’s World Program of Action concerning Disabled Persons in 1982 emphasized the necessity of eliminating physical, social, and cultural barriers impacting the lives of disabled individuals, thereby expanding the scope of accessibility design to encompass a broader socio-cultural and supportive framework [3]. Countries with early and widespread implementation of accessibility legislation and infrastructure include United States of America, Sweden, Denmark, and Japan. In contrast, China first proposed the construction of accessibility facilities in 1985, marking a delayed start and slower development compared to Western developed nations. Although accessibility facilities are relatively common in major urban public buildings, their overall coverage and usage rates remain low. The revised China Accessibility Design Standards of 2012 (GB 50763-2012) established more comprehensive construction requirements. In 2021, China’s 14th Five-Year Plan for the Protection and Development of Disabled Persons identified accessibility construction as a significant civil engineering project to foster a universal social atmosphere. The "People’s

Republic of China Accessibility Environment Construction Law" enacted in 2023 legislates comprehensive requirements for accessibility, ensuring services for people with disabilities. With China's rapid economic growth and the substantial enrichment of its citizens' material and spiritual lives, accessibility construction has extended far beyond traditional building facilities to include technological research, urban-rural development, healthcare, education, and cultural dissemination. Data from the seventh national census in China revealed that the total number of disabled individuals in the country was 85 million, encompassing around 27.8 million with hearing impairments, 16.91 million with visual impairments, and 29.77 million with physical disabilities [4]. The population aged 60 and above in both urban and rural areas amounted to 260 million, constituting 18.7% of the total, while the population aged 65 and above was 190 million, representing 13.5% of the population. Approximately 149 cities had entered an advanced aging phase. Drawing from past trends, it was projected that the number of disabled and semi-disabled elderly individuals would surpass 40 million in addition to the 416 million individuals without internet access and a notable cohort with cognitive impairments. These demographics increasingly seek top-notch urban accessibility. Confronted with these challenges, universal design has emerged as a cornerstone of human settlements and an essential element of the national livelihood security strategy, which embodies aspirations for societal fairness and justice, along with a profound reverence and consideration for human well-being. Therefore, elevating the technological sophistication of barrier-free construction is imperative, allowing it to play a significant role in advancing a prosperous society and enhancing life quality of people.

Universal design should embody seven fundamental principles including equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and appropriate size and space [5]. On-site examinations of various indoor and outdoor workstations and fitness equipment for wellness show that outdoor park workstations generally offer fixed seating for resting and a flat surface for reading and entertainment. Typically, these workstations consist of a four-legged steel frame supporting a square tabletop, and the chairs are either L-shaped or linear benches fixed around the tabletop. While functional, they lack flexibility for other uses. Wellness center equipment is more specialized, targeting joint stiffness and mobility issues in users' lower limbs, but does not incorporate seamless transitioning capabilities. Community area equipment such as waist twisters, walking machines, step machines, and exercise bikes provide basic leisure exercise functions but lack functional versatility, often occupy a large area, and are usually situated far from seating areas, indicating a deficiency in universal design.

This study primarily focused on the universal design principles to develop a multi-functional wellness device that integrated leisure and rehabilitative fitness to meet daily needs with a range of versatile devices catering to individuals with disabilities. These devices seamlessly switched between functions, serving as both a workstation chair, a work surface, and a platform for coordinated physical exercise without necessitating user relocation, which enabled users not only to carry out tasks at a work surface, but also to participate in coordinated physical activities from the same position, thereby providing more humane services for leisure and entertainment to individuals with disabilities as well as others.

Materials and methods

Structural design of the workstation chair

(1) Anthropometric percentiles

When incorporating human body dimensions into product designs, the fundamental guide for establishing the functional measurements of a product lies in anthropometric percentiles [3]. Anthropometric data is often represented as percentiles (PK), which function as both a

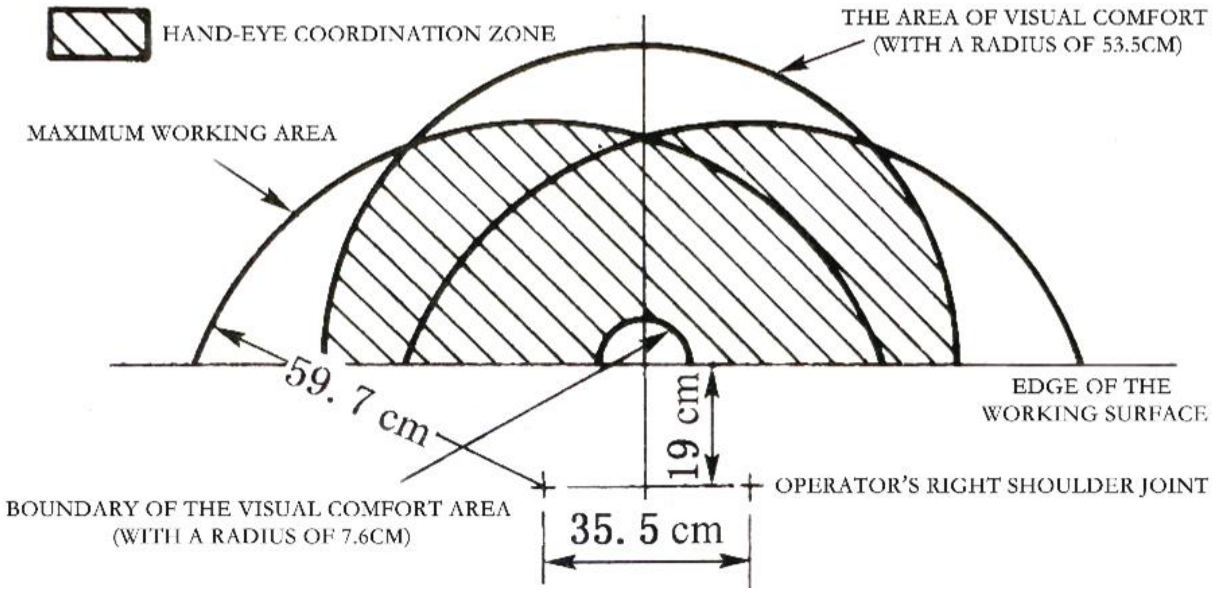
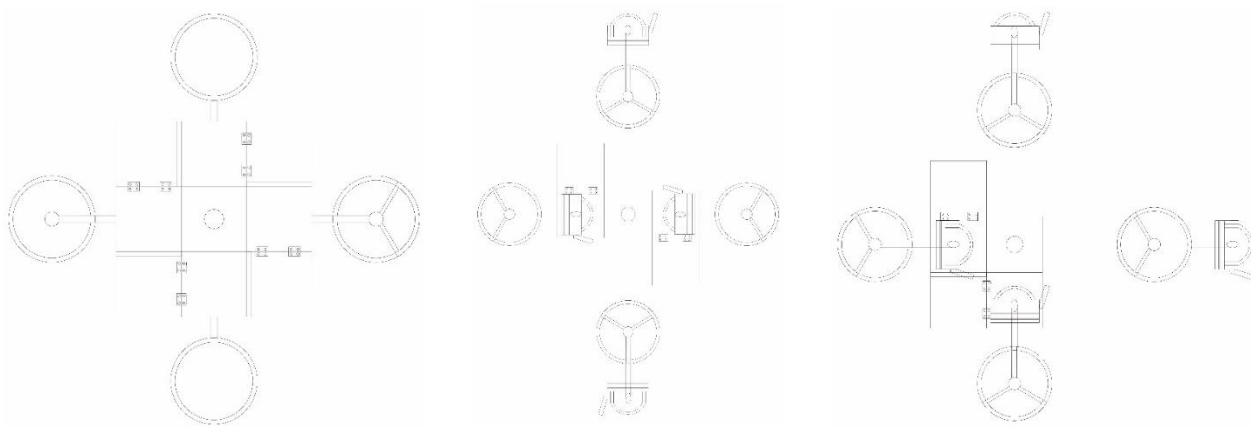


Figure 1. Schematic diagram illustrating the layout of the horizontal working surface area.

positional indicator and a threshold value for body measurements. The most frequently utilized percentiles in design are P_5 (indicative of smaller stature), P_{50} (indicative of average stature), and P_{95} (indicative of larger stature). In accordance with the national standard "Application of percentile principles for human body dimensions in the design of products" (GB/T12985-91) [6], this proposed product aimed to cater to users of varying statures and falls under type III products, thereby necessitating the utilization of the 50^{th} percentile (P_{50}) as the foundational basis for its dimensional design.

(2) Tabletop design

Tabletops can vary widely based on specific work requirements such as electronic control consoles for automated production systems, office desks for professional use, and study desks for students. The objective of this study was to create a product that integrated daily needs like learning, dining, and entertainment for the target user group. The innovation was embodied in its modular and detachable nine-grid tabletop design. A schematic representation of the layout of the working surface area on one side of the table was shown in Figure 1. The tabletop design for this study took on a square shape, allowing for up to four individuals to be seated on one side (Figure 1). The functional dimensions of the tabletop were derived from the anthropometric data of male users at the P_{50} percentile, aiming to meet the general human workspace design requirements. In accordance with the age range of 18 - 60 years, the national standard "Human Body Dimensions for Workspace" (GB/T13547-92) stipulated that the seated reach for males at the 50^{th} percentile was 834 mm [6]. When establishing the overall dimensions of the tabletop, additional adjustments for functional and psychological factors should be taken into consideration. Typically, the recommended height range for a tabletop intended for writing in a seated position was between 650 mm and 910 mm. In this design, where the product necessitated five supporting points for stability, the tabletop height was set at the upper limit of this range. The innovation of this tabletop design was in its modular and deconstructable nine-grid structure, comprising nine small table sections. The central small table board was affixed to the central column, which held the product's weight with screws, making it non-flippable and immovable. The four small table boards positioned above, below, to the left, and to the right of the central board were secured onto U-



(a) (b) (c)

Figure 2. Complete assembly in a nine-grid pattern (**a**), assembly of adjacent table boards (**b**), assembly of neighbor table boards (**c**).

shaped brackets on the backrests of the four circular seats of the product. Each of these small table boards was paired with an adjacent corner table board using a single-sided dovetail joint with the two boards in each pair connected by hidden folding hinges, allowing them to fold and lock together face-to-face. This configuration enabled the tabletop to be fully assembled in a nine-grid pattern (Figure 2a). Alternatively, it could be assembled with the opposite table board (Figure 2b), or with adjacent table boards (Figure 2c).

(3) Chair design

The chair design evoked the aesthetics of a bar stool, elegantly elevated from the ground to a specific height. This design showcased a footrest and rotational capabilities. Notably, the backrest and tabletop formed an integrated structural unit, harmonizing functionality and form. The chair's design was rooted in the supportive structures of the human body while seated, notably considering the spine, pelvis, legs, and feet. Extensive scrutiny and analysis had underpinned this chair's development. Initially, attention was directed to the human spine with a balanced sitting posture entailed even pressure distribution on the intervertebral discs, whereby muscles bear a consistent static load. The comfort of the seated position was intrinsically linked to the natural physiological curve of the lumbar region, which necessitated an angle exceeding 90° between the upper body and thighs, accompanied by lumbar support, a foundational element leveraged through the adept manipulation of the adjacent tabletop boards. Subsequently, while seated, the ischial bones and thighs bear the brunt of pressure. However, the ischial bones, being more robust, can endure heightened pressure, while the lower thighs host a network of blood vessels and the nervous system. Excessive pressure can impede blood circulation and nerve conduction, leading to discomfort. Consequently, the chair's seat was designed with varying pressure distribution across different zones of the buttocks. The optimal pressure distribution on the seat was shown in Figure 3 with curved lines delineating equidistant pressure zones. Pressure units amounted to 102 Pa with the graph denoting that pressure on the ischial bones should range between 8 - 15 kPa, gradually decreasing to 2 - 8 kPa at the contact boundaries [7]. When employing rigid seat materials, the surface structure should align with the pressure distribution. Conversely, the use of soft cushioning materials entailed automatic deformation under body pressure [8]. In this design, the seat adopted the latter approach, utilizing soft cushioning materials. The chair was composed of four sets, each encompassing three core elements including the seat, lumbar support, and frame, which necessitated five pivotal points for stabilization. These crucial anchoring points featured a central pillar upholding the central tabletop within a mesh configuration, alongside four distinct columns supporting the quartet of seats individually. The structural framework of the chair comprised columns, L-shaped braces, and C-shaped footrests. The lower extremity of the L-shaped brace was seamlessly welded to a sheath that encased the chair's bottom column, facilitating unfettered rotational movement in a horizontal plane around the column. Positioned at the apex of the L-shaped brace, there existed a vertically adjustable U-shaped lumbar support bracket, offering a versatile range from 0° to 270° in conjunction with an angle fixation mechanism. The lumbar support mechanism was fashioned by the folding and rearrangement of two adjacent tabletop boards, subsequently affixed to the U-shaped lumbar support bracket. The angle fixture device not only customized and secured the optimal angle for lumbar support, tailoring to the lumbar curvature and support requisite across varied seating positions, but also ensured the evenness of the amalgamated mesh tabletop. The structural blueprint of the chair frame was visually annotated in Figure 4.

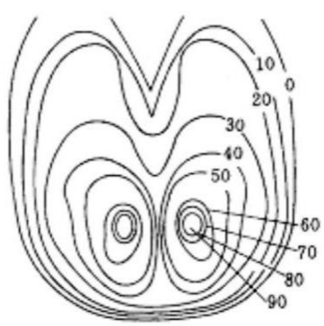


Figure 3. The curve of body pressure distribution in a seated posture.

Material and color studies of workstation chairs

The color design of workstation chairs was influenced by several factors including the materials used, processing technology, the physical and color functionality of the product, environmental conditions, and ergonomics. The design employed steel plate for the frame structure, composite plastic wood for the tabletop, and fiberglass for the seat surface. The inherent scarcity of colors in these materials coupled with the visual imperfections introduced by welding, cutting, and thermal bending during processing necessitated comprehensive color design studies when selecting materials.

(1) Material characteristics

Steel tubing (Baotuo Industry Co., Ltd., Shenzhen, Guangdong, China) was used as steel frame materials in this design, which stood as a prevalent choice for outdoor tables and chairs, primarily due to its structural integrity and support capabilities. To withstand outdoor elements, the steel surface underwent hot-dip galvanization followed by an outdoor powder coating application, effectively thwarting rust and corrosion. Stainless steel was utilized for the connecting screws, providing exceptional rust resistance. Plastic wood (Mujia Material Science and Technology Co., Ltd., Tianjin, China), an emerging composite material both in China and internationally, was used as tabletop materials in this study and was crafted by extruding polypropylene, wood fiber, additives, and pigments within a mold. This material showcased excellent water resistance, minimal water absorption, and resistance to corrosion, wear, and weathering. It maintained its durability outdoors, remaining intact without succumbing to breakage or pest infestation. Its malleability and cost-effectiveness in comparison to solid wood had made it a favored option for outdoor tables, chairs, park benches, and similar applications. Fiberglass (Hongyi Da Furniture Co., Ltd., Shanghai, China) comprising glass fibers, carbon fibers and a resin matrix, boasts robust corrosion resistance and enduring exposure to air, water, as well as typical concentrations of acids, bases, and salts was used for seat material in the design. This material provided exceptional design flexibility, enabling the crafting of products with diverse structures tailored to specific application requirements. Fiberglass

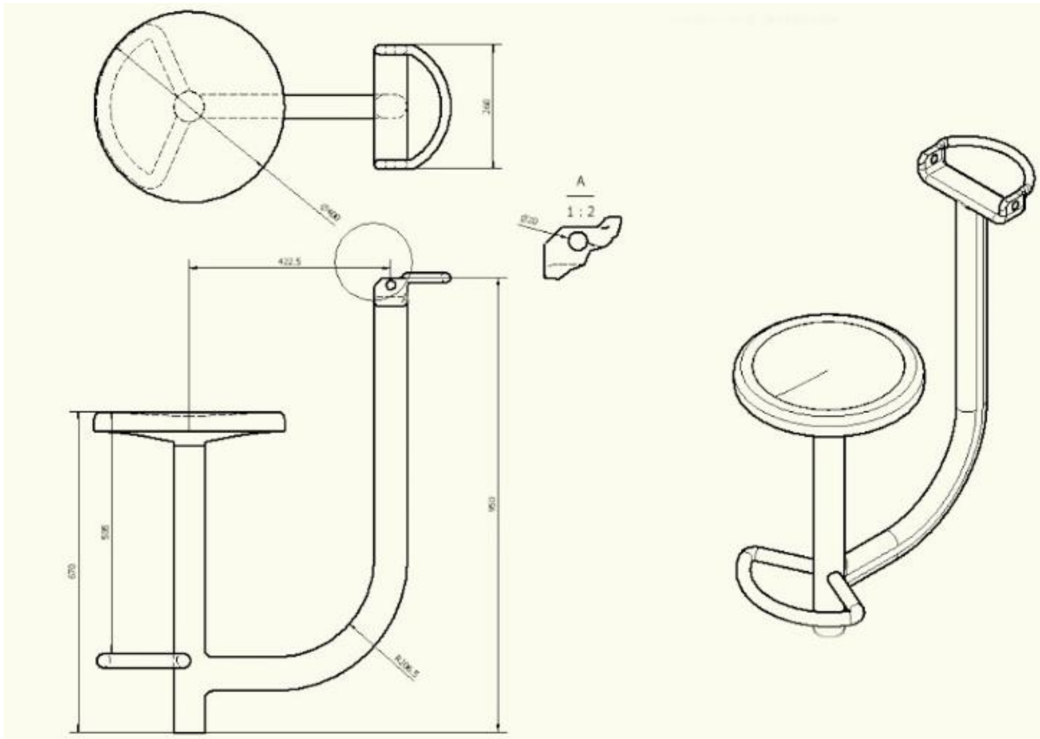


Figure 4. The frame structure of the chair.

items exhibited precise dimensions, smooth surfaces, consistent specifications, and stable quality, rendering them ideal for automated and mechanized production processes.

(2) Color design

Effective color design in product decoration can significantly enhance users' satisfaction, whereas a poor color scheme may induce aversion and negatively impact product sales. Raw materials typically exhibit inherent colors, such as the iron gray of steel, the brownish yellow of sheet metal, and the metallic hues of connectors. These colors are varied and often lack a coherent system. The natural colors of these materials combined with their processing methods frequently result in final products that are aesthetically unappealing. Consequently, a thorough color analysis and thoughtful color scheme design are essential to enhance the visual appeal of the products, creating user expectations that extend beyond mere functionality. Colors play a pivotal role in conveying information to users during the product perception process, establishing a psychological color resonance between users and the product [9]. Typically, a color scheme incorporating fewer than three colors cultivates a cohesive tone and a powerful overall impression. In contrast, utilizing more than three colors can fragment and complicate the product, overwhelming the visual senses, and leading to inappropriate color utilization. This results in a lack of harmonious and unified color decoration effects, hindering the establishment of a psychological color resonance with users [10]. Considering that the intended audience for this design included vulnerable groups such as individuals with disabilities and the elderly among others, it was important to note that visually impaired individuals might have limited color recognition abilities but were particularly responsive to color schemes with pronounced contrasts. Recent trends indicated a shift in the color preferences of the elderly towards vibrant colors with heightened contrast. Therefore, drawing from the analysis and incorporating color scheme theories, complementary color relationships were identified. Notably, the most prevalent complementary relationships included red-green, orange-blue, and yellow-purple. Among these, the yellow-purple combination was aesthetically pleasing due to its optimal brightness contrast, fostering a sense of depth, and enhancing the product's three-dimensional appearance [11]. Once the color relationships were established, the allocation of yellow-purple areas should adhere to the harmony method based on area contrast [12]. According to Munsell, achieving color balance primarily relied on the proportional area of each color. Colors with higher intensity should cover smaller areas, while colors with lower intensity should cover larger areas. Given that purple had a lower lightness, it imparted a sense of stability. Therefore, the five supporting pillars of the product were designed in purple to enhance the visual perception of stability [13]. For the nine-grid tabletop, the color scheme involved setting the top and bottom faces of five table sections to purple with the remaining sections in yellow, creating a checkerboard-like pattern. This resulted in a dominant purple presence, complemented by smaller areas of yellow, regardless of whether the product was presented in disassembled (Figure 5) or assembled modes (Figure 6). This design approach imparted a sense of stability, volume, and dynamism to the product. It aligned with the product’s characteristics and met the color psychology expectations of the target user group.

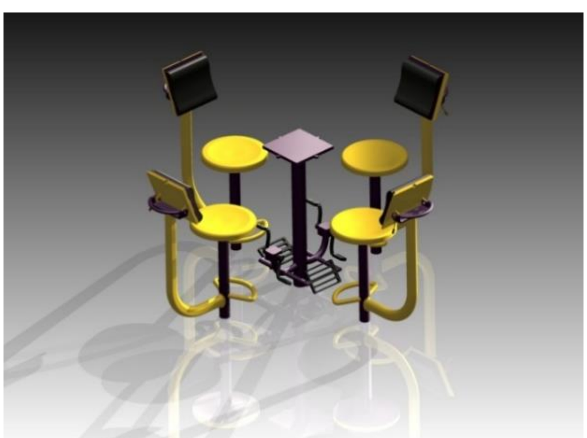


Figure 5. Visualization of the disassembled mode.

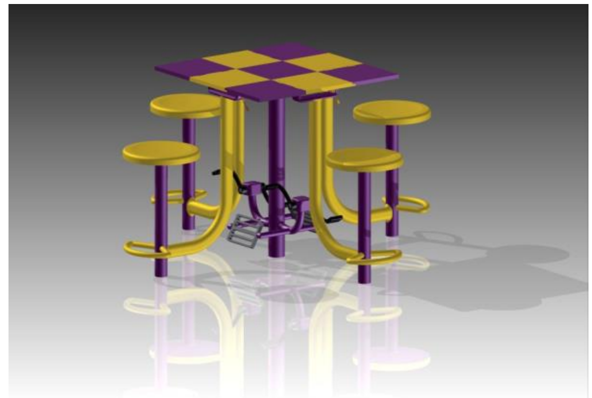


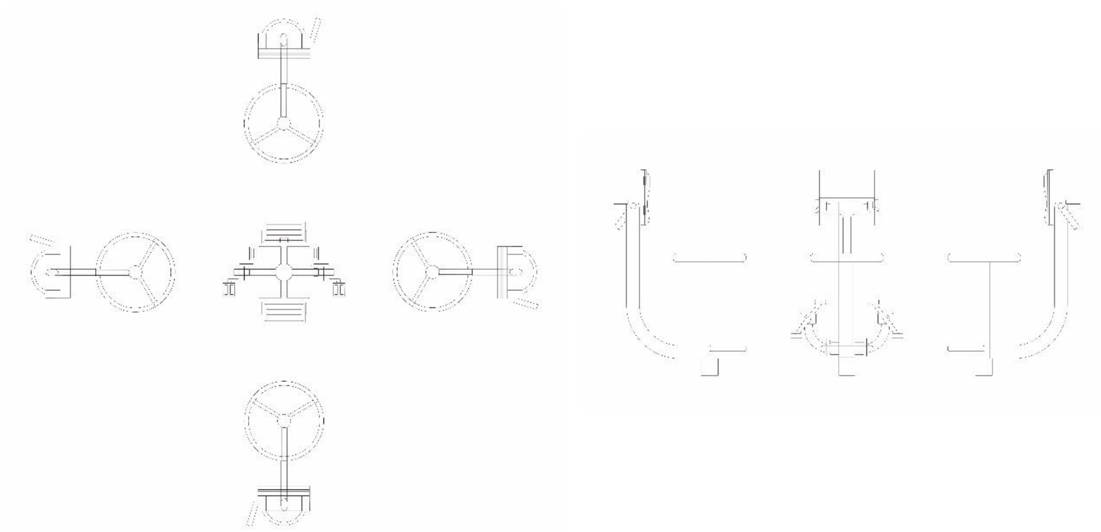
Figure 6. Visualization of the assembled mode.

Results and discussion

Functional transformation between seat and tabletop

The central tabletop in the grid layout remained stationary, while the other eight tabletops were arranged in pairs. By folding them face-to-face and securing them with a snap-in bead, they could be rotated along the U-shaped lumbar support bracket to form a backrest. The angle could be adjusted and fixed to achieve a comfortable position, creating the chair mode (Figure 7). In this configuration, the nine-grid tabletop was disassembled, allowing users to perform rehabilitative exercises for their legs and ankles while seated. Beneath the central column were rotating foot pedals for ankle exercises and bicycle pedals for leg muscle workouts, providing relief from lower body pressure after prolonged desk work or leisure activities. To revert to the tabletop configuration, the backrest was flipped to a horizontal state, and the two face-to-face fitted tabletops were opened, which allowed for the reconfiguration of the four sets of tabletops and the central column tabletop into a grid layout (Figures 5 and 6). The optimal functional dimensions of the tabletop were set at 900 mm × 900 mm with each individual panel measuring 300 mm × 300 mm, and the tabletop height from the ground set at 910 mm.

Analysis of the psychological impact of colors



(a) (b)

Figure 7. Seat mode with top view (**a**) and side view (**b**).

According to "The sensation of color is the most universal form of aesthetic experience" [14], individuals tended to be more attuned to the emotional impact of colors compared to graphic or textual emotions. Studies indicated that, within the extensive consumer market, particularly with homogeneous products, individuals initially focused on the color of an object. This initial perception process typically lasted for 3 - 5 seconds, after which their attention might then shift to other design elements. Colors can be classified into achromatic colors and chromatic colors based on their physical properties. Chromatic colors encompass red, orange, yellow, green, cyan, blue, and purple along with various combinations of these colors in different proportions. They exhibit the fundamental attributes of color including hue, brightness, and saturation, thereby conveying a distinct sense of color. In contrast, achromatic colors consist of black, white, and different shades of gray achieved through the blending of black and white. Achromatic colors solely possess the attribute of brightness, lacking hue and saturation, and thus do not convey specific color tendencies. Due to these distinctions, observers are more psychologically impacted by chromatic colors, leading to a range of psychological and emotional responses. For instance, red may evoke feelings of joy or danger, orange may evoke happiness or sweetness, yellow may evoke sunshine or brightness, blue may evoke depth or tranquility, and purple may evoke mystery or nobility. These reactions stem from the immediate perception of the physical attributes of colors. Individual colors can trigger corresponding psychological and emotional experiences, while combinations of colors can have an even more profound impact on human psychology and emotions. Consequently, the complexity of color scheme design lies in its potential to influence individual psychology and emotions, highlighting the intricate nature of color selection and its psychological ramifications.

The design of this product seamlessly blended structure, functionality, form, and color in a cohesive and harmonious manner. Users could effortlessly transition between the nine-grid tabletop assembly and the rotatable chair function, facilitating barrier-free transformations and enhancing the product's human-centered design. By refining the structure and employing human-machine ergonomic analysis for workstation chairs, combined with material and color psychology, the product's functional design was conceived. Simple operations enabled the transformation of the seating and table surfaces to accommodate diverse user needs. The chair's backrest formed an integral part of the tabletop structure, enabling the work surface to be reconfigured into various shapes such as a full nine-square grid, a Z-shaped arrangement opposite another table, or a linear configuration adjacent to another table. This design catered to daily needs such as studying, dining, and entertainment, offering accessibility services for individuals with disabilities and introducing new dimensions to the wellness manufacturing industry.

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