AN ANTHROPOMETRIC AND ERGONOMIC EXAMINATION ON TIN PACKAGING

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Keywords

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Abstract

Packaging design extends beyond physical protection, integrating biomechanical functionality, anthropometric compatibility, and user safety. Despite superior mechanical durability, metal packaging presents significant ergonomic limitations in user interaction due to rigid forms, low friction surfaces, and high opening torque requirements. Utilizing a Multiple Case Study model and "criterion sampling," this research examines three "limit case" typologies representing distinct physical scales and biomechanical requirements: (1) 5L olive oil tin (Cylindrical Grip), (2) 140g tuna can (Lateral Grip), and (3) 10g lip balm tin (Tip Grip). Data was collected via a Structured Expert Review. Samples were analyzed across (1) Anthropometric/Geometric Compatibility, (2) Functional/Biomechanical Interaction, and (3) Safety/Inclusive Design, utilizing literature-defined torque equations and statistical thresholds reflecting local hand morphology (Brachycheiry/Mesocheiry). Findings reveal that designs exhibiting anthropometric incompatibility—even in the "Best-Case Scenario" based on healthy young adults—violate accessibility boundaries for disadvantaged groups, causing potential physical strain.

TENEKE AMBALAJLAR ÜZERİNE ANTROPOMETRİK VE ERGONOMİK BİR İNCELEME

Anahtar Kelimeler

Ambalaj ergonomisi
Teneke ambalaj
Biyomekanik işlevsellik
Uzman incelemesi
Kavrama biyomekaniği

Öz

Ambalaj tasarımı; fiziksel korumanın ötesinde biyomekanik işlevsellik, antropometrik uyum ve kullanıcı güvenliğini bütünleştirir. Metal ambalajlar, üstün dayanıklılıklarına rağmen; rijit formları, düşük sürtünmeli yüzeyleri ve yüksek açma torku gereksinimleriyle ciddi ergonomik sınırlar oluşturur. Çalışma, metal ambalajların ergonomik performansını Çoklu Durum Çalışması (Multiple Case Study) ile incelemektedir. 'Ölçüt örnekleme' yöntemiyle, farklı fiziksel ölçek ve kavrama gereksinimlerini temsil eden üç 'limit durum' belirlenmiştir: (1) 5L zeytinyağı tenekesi (Silindirik Kavrama), (2) 140g ton balığı kutusu (Yanal Kavrama), (3) 10g dudak kremi kutusu (Hassas Uç Kavrama). Veriler Yapılandırılmış Uzman Değerlendirmesi ile toplanmıştır. Örneklemler; yerel el morfolojisini (Brachycheri/Mesocheri) yansıtan istatistiksel eşikler ve tork denklemleri kullanılarak; (1) Antropometrik/Geometrik Uyumluluk, (2) Fonksiyonel/Biyomekanik Etkileşim ve (3) Güvenlik ve Kapsayıcı Tasarım eksenlerinde analiz edilmiştir. Bulgular, "sağlıklı genç yetişkin" verilerine dayalı 'En İyi Durum Senaryosu'nda dahi uyumsuzluk gösteren tasarımların, dezavantajlı grupların erişilebilirlik sınırlarını ihlal ederek potansiyel fiziksel zorlanmalara zemin hazırladığını ortaya koymaktadır.

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1. Introduction

In the historical process, packaging design has transcended its role as a mere passive shell providing protection against environmental factors, evolving into a multidimensional system that manages the physical and cognitive interaction between the user and the product. This evolution, which began with natural materials in 8000 BC (Becer, 2014), gained a mass dimension with the Industrial Revolution and the introduction of materials suitable for industrial production (Calver, 2007). Today, packaging functions as a critical interface at the level of "primary packaging," where the consumer interacts directly with the product, extending beyond the secondary and tertiary layers that ensure product safety during logistics processes (Aygün, 2007).

The physical quality of this interface is shaped by the type of material employed. In the literature, packaging materials are categorized into main groups: paper-cardboard, glass, metal, plastic, and composites (Özden and Sönmez, 2024), with each material type offering specialized physical properties according to its intended use. Among these materials, metal-based packaging holds strategic importance in the food and cosmetic industries due to technical advantages such as hermetic sealing, creating a complete light barrier, gas impermeability, and superior mechanical durability (Arıkan, 2011). Tin cans, composed of tin-coated steel sheets frequently preferred in the packaging industry, offer a long shelf life by providing chemical stability (Erdal, 2024), while also becoming a reason for consumer emotional preference in recent years due to their aesthetic and nostalgic appearance (Koç, 2015).

However, the rigid structure and high mechanical durability that metal packaging possesses to protect the enclosed product can transform into an ergonomic resistance when user interaction is involved. The technical success of the packaging regarding shelf life unfortunately does not always correspond to the functions of "openability" and "graspability." At this precise point, Ertem (1999) emphasizes that the packaging form should be addressed not only as a visual or protective element but also as a functional structure responding to user limbs. Similarly, Önlü (2004) points out that the success of the design is determined as much by ease of use as by aesthetic integrity. Consequently, the smooth surfaces and hard forms in metal packaging, while protecting the product perfectly, may harbor design flaws that challenge the biomechanical limits of the human hand.

The origin of this design problem is explained in the literature through "Grip Biomechanics." Rowson and Yoxall (2011) express that the torque (T_H) required to open a package relies on a delicate balance between surface friction and grip force with the following equation:

$$T_H = \mu_{\{CH\}} \cdot N_H \cdot r_C \qquad (1)$$

In the equation (1); T_H denotes the Resulting Torque, μ_{CH} represents the Friction Coefficient between the hand and the closure, N_H signifies the Applied Grip Force, and r_c indicates the Closure Radius.

Equation (1) mathematically demonstrates that the low friction coefficient (μ_{CH}), which emerges upon human hand contact due to the inherently smooth nature of metal surfaces, necessitates the user to apply a significantly higher grip force (N_H) to open the lid or carry the can. In light of current research, this mechanical disadvantage created by smooth metal surfaces increases the risk of slippage and muscle load, particularly in cases where the palmar contact area is reduced (Rowson and Yoxall, 2011).

The success of the design depends on the compatibility of these biomechanical requirements with the physical measurements (anthropometry) of the target audience. Studies conducted specifically in Turkey (Bayraktar and Özşahin, 2018; İnce Parpucu et al., 2023) reveal a direct correlation between hand anthropometry and grip capacity. Within the scope of this study, to numerically audit the ergonomic suitability of the examined tin packaging, the comprehensive hand anthropometry data for the Turkish population by Bayraktar and Özşahin (2018) was accepted as the "benchmark." The recent study by İnce Parpucu et al. (2023) was evaluated as a complementary source supporting the correlation between hand dimensions and grip force.

Although studies in the literature generally focus on the visual perception of packaging and consumer preferences, the structural analysis of metal packaging requiring different hand functions and grip types remains limited. To determine the anthropometric and biomechanical compatibility of metal packaging forms, this study focuses on a Structured Expert Review based on ergonomic criteria by adopting an object-oriented methodology. Accordingly, by examining packaging typologies representing the different functional capacities and biomechanical limits of the human hand through a comparative case analysis method, the research aims to analyze the anthropometric compatibility of the designs, the effect of surface characteristics on grip safety, and potential physical strain points.

2. Scientific Literature Review

Research conducted on packaging design and ergonomics reveals that the subject is a multidimensional discipline encompassing material science, biomechanics, and anthropometry. The fundamental literature examined within the scope of this study is detailed below, starting from the functional definition of packaging and extending to material constraints, biomechanical challenges, and anthropometric requirements.

In the study titled “The Importance of Anthropometry in Design” authored by Kaya and Özok (2017), the necessity of considering human characteristics in product and environmental design was emphasized, and the determining role of anthropometric data in the ergonomic design process was examined. The problem statement is based on the premise that products must not only be aesthetic, functional, and technological but also designed in accordance with the physical measurements of the individuals who will use them. The aim of the study was to compile anthropometric studies conducted in Turkey and to demonstrate how this data can be utilized in ergonomic design by examining its change over time. Based on this, anthropometric measurements conducted for different age and gender groups from the past to the present were analyzed using the literature review method. The research compared various anthropometric studies carried out in Turkey since 1917, specifically basing its analysis on large-scale research conducted on industrial workers in 1981 and by TurkStat (TÜİK) in 2005. Numerous physical measurements of individuals, such as height, weight, head height, and bust height, were determined and presented as data to be considered in product, machine, and environmental designs. The findings showed that ergonomic design is a factor affecting not only product functionality but also user comfort, health conditions, and productivity. Furthermore, it was highlighted that the use of foreign country anthropometric data in design could create problems specific to Turkey. The study makes a significant contribution to the literature by drawing attention to the importance of ergonomic design suitable for the local user profile through the compilation of anthropometric data specific to Turkey. It has been used as a reference in this study as it grounds the necessity of considering local anthropometric measurements, especially in product groups such as metal packaging where physical contact with the user is intense.

In the article titled “Metal Packaging in the Food Sector” by Erdal (2024), the reasons for using metal packaging in the food sector, along with its advantages and environmental impacts, were examined. In this study based on a literature review, the oxygen, moisture, and light impermeability properties provided by metal, especially in the packaging of long-life products such as canned food, tomato paste, and oil, were emphasized. Additionally, it was explained why metals like aluminum and steel are preferred in food packaging due to their hygienic, durable, and recyclable structures. The article stated that environmental sustainability criteria are gaining increasing importance in the selection of packaging materials, concluding that metal packaging offers not only a protective but also an environmentally friendly solution. It was also noted that metal packaging in the food sector ensures safe and long-life usage through sterilization and lacquer coating methods.

The research article titled “Relationship between Anthropometric Characteristics of the Hand, Grip Strength, and Manual Dexterity in Healthy Young Individuals” was published by Tuba İnce Parpucu et al. in 2023. The study examines the relationship between hand anthropometry, grip strength, and hand dexterity in young adults and reveals how these parameters change according to factors such as gender, body mass index (BMI), and hand dominance. The scope of the study aimed to create a basis for clinical and ergonomic evaluations by addressing not only the physical dimensions of the hand but also its functional capacity. In the application section of the study, anthropometric measurements such as hand length, width, and span length of 197 healthy university students aged 18-25 were evaluated with a tape measure; grip strength with a dynamometer; and hand dexterity with the Nine-Hole Peg Test (NHPT). According to the findings, the anthropometric measurements and grip strengths of males were found to be significantly higher than those of females; and it was determined that the anthropometric values of left-hand dominant individuals were higher. Furthermore, while a strong positive correlation was detected between hand dimensions and grip strength, a moderate relationship was observed with hand dexterity. The article contributes to the literature by emphasizing that not only force but also anthropometric characteristics and functional tests should be evaluated holistically in hand rehabilitation and ergonomic designs.

The master's thesis titled “Ergonomic Consumer Product Design: Principles, Evaluation and Application” was prepared by Sercan Madanlar in 2019. This study presents a systematic principle and evaluation model that can be used in the design of ergonomic consumer products. In the thesis, ergonomics is handled not only as limited to physical comfort but also as a strategic element in terms of user satisfaction, product performance, and new product development processes. The "Ergonomic Consumer Product Design Principles" developed within the scope of the study were classified as primary (health, durability, comfort, etc.) and secondary (price, style, environmental impact, etc.) criteria; these principles were supported by a conceptual model aiming to establish a balance between user expectations and product ergonomics. In the application section, 11 different pruning shears were evaluated through user tests and physical measurements; the effect of individual differences such as hand size and gender on the perception of ergonomics was statistically analyzed. The thesis contributes to the literature particularly with its user-based test methods and systematic principle proposal, creating an applicable, structured framework for ergonomic product evaluation. In this respect, it qualifies as a model that can be used in the ergonomic analysis of the tin packaging addressed in this research.

The article titled “Hold, grasp, clutch or grab: Consumer grip choices during food container opening” was authored by J. Rowson and A. Yoxall in 2011. This study examines the grip strategies consumers use when opening jars and packaging lids within the framework of the concept of "openability" and the perspective of inclusive design. The article analyzes the relationship between packaging accessibility and factors such as physical strength, friction coefficient, and lid diameter, especially for the aging population and female users. Within the scope of the research, the forces applied and the grip styles preferred (spherical, cylindrical, lateral, etc.) by 34 participants (19 female, 15 male) when opening lids with diameters of 55, 75, and 110 mm were tested using a specially designed Human Torque Device. As a result of the application, it was determined that women generally preferred the "spherical grip" to generate maximum torque rather than for comfort, yet many still struggled to open the lids; whereas men were able to make comfort-oriented choices using a wider range of grips. The study provides important data for ergonomic product development processes by arguing that not only dimensions but also friction surfaces and gender-dependent strategic grip preferences of users must be considered in packaging design.

The study titled “Anthropometric measurement of the hand” was published by Nuriye Kübra Bayraktar and Esin Özşahin in 2018. This research aims to create a hand anthropometry database specific to the Turkish population and to determine gender differences by classifying the obtained data according to the Krogman Hand Index. In the study, hand measurements were treated as strategic indicators that can be used not only as anatomical data but also in fields such as ergonomic design, identification (forensic medicine), and gender distinction. In the material and method section of the research, the hand length and hand width of 141 healthy right-handed students (49 male, 92 female) were measured with a digital caliper, and their body mass indices were recorded. As a result of the analyses, it was observed that male hand dimensions were statistically significantly larger than those of females; according to the Krogman Index, male hands were classified as "Brachycheiry" (short and broad), and female hands as "Mesocheiry" (medium). The study proves that hand dimensions vary across societies depending on genetic and environmental factors and presents a model emphasizing the necessity of using population-specific data rather than universal standards in ergonomic product designs and forensic science studies.

The study titled “Research methodologies for assessing the ergonomics of packaging products – a review” was authored by Bošnjaković and Vladić (2020). In this review article, various research methods for evaluating ergonomic criteria in packaging design were compiled, and current approaches were systematically examined. The problem addressed by the article is that poorly designed packaging creates physical difficulties and dissatisfaction for users. In this context, the aim of the study is to contribute to making products user-friendly by defining subjective, mechanical, objective, and usability-oriented research methodologies that can be used in the assessment of packaging ergonomics. The research does not define a direct experimental universe or sample; it is rather in the nature of a literature review based on findings and methods obtained from previous studies.

The literature presents independent and valuable studies on the material mechanics of metal packaging, anthropometric data modeling, and biomechanical torque principles. However, a holistic modeling study synthesizing the ergonomic resistance of industrially produced metal packaging along the axes of friction coefficient, geometric form factors, and local anthropometric constraints has not been encountered. This study aims to fill this critical gap between global design standards and local user morphology with a multidimensional analysis model based on objective data.

3. Methodology

3.1. Purpose and scope of the study

The primary objective of the research is to evaluate the extent to which metal (tin) packaging designs meet the criteria of biomechanical functionality and anthropometric compatibility, transcending industrial priorities such as manufacturability and shelf life. Within the scope of the study, the selected tin packaging samples will be examined in light of the torque principles (T_H) defined by Rowson and Yoxall (2011) and the critical threshold values derived from current anthropometric data belonging to the local population (Bayraktar and Özşahin, 2018; İnce Parpucu et al., 2023), and the physical strain points and safety risks created by the designs will be analyzed.

The scope of the research is limited to the ergonomic performance analysis of tin packaging samples selected from canned food, liquid oil, and cosmetics, representing the three fundamental motor functions of the human hand (cylindrical, lateral, and tip grip), and the findings were obtained through the Structured Expert Review protocol.

3.2. Research model

This study employs the Multiple Case Study model, one of the qualitative research designs. This design allows for each case to be analyzed holistically within itself first, and subsequently, to reach more comprehensive results by making cross-case comparisons (Yıldırım and Şimşek, 2016). In this context, the three selected packaging typologies were first evaluated within their own structural parameters and then comparatively analyzed in terms of their ergonomic performances.

The technical evaluation of the designs was carried out through a Structured Expert Review process conducted by a single researcher holding a bachelor's degree in the Industrial Design discipline and currently pursuing academic specialization in the field of Packaging Technologies. The evaluation was guided by biomechanical principles accepted in the packaging ergonomics literature (Rowson and Yoxall, 2011) and current Turkish population anthropometric datasets (Bayraktar and Özşahin, 2018). Conducting the process by a single expert with a standardized audit protocol ensured the preservation of uniformity of criteria and methodological internal consistency during the analysis phase.

The study is based on the Objective and Mechanical Assessment protocols, which Bošnjaković and Vladić (2020) classify in the literature as "fundamental methodologies providing objective data." This approach grounds ergonomic performance evaluation on verifiable data based on biomechanical principles, anthropometric datasets, and the measurable structural parameters of the product, rather than user feedback which may contain subjective variability. The research relies on an objective theoretical evaluation model that intersects the physical form of the packaging with the physical limits of human anatomy and the structural parameters of the product on a geometric plane.

3.3. Evaluation Criteria and Analysis Axes

To ensure the methodological consistency of the Structured Expert Review process, all packaging samples were holistically analyzed on three main axes determined in line with models in the literature. Within the scope of the first axis, Anthropometric and Geometric Compatibility; the relationship and physical fit of product dimensions (diameter, grip span, etc.) with local hand morphology data were examined. In the second axis, Functional and Biomechanical Interaction; the friction coefficient and force requirements were evaluated from a biomechanical perspective, taking the Rowson and Yoxall (2011) torque formula as a basis. Finally, in the last axis, Safety and Inclusive Design; physical parameters of the packaging, such as sharp edge risks, the narrowness of contact surfaces, and surface slipperiness, were evaluated as potential physical strain points within the framework of determined anthropometric threshold values.

3.4. Research questions

In line with the purpose of the study, the fundamental research questions, which ground the case analyses on a theoretical basis (Rowson & Yoxall, 2011) and local data, are structured according to the determined analysis axes as follows:

Q1 (Anthropometric Axis): Are the lid and body geometries of the examined tin packaging compatible with the hand morphology (Brachycheiry/Mesocheiry) and anthropometric measurements of the local population?

Q2 (Biomechanical Axis): Do the surface friction coefficients (μ_{CH}) and radii (r_C) of the packaging challenge the biomechanical limits according to the torque formula (T_H) defined in the literature?

Q3 (Safety and Inclusive Design Axis): In designs requiring different grip types (Cylindrical, Lateral, Tip), how do variations in product size and usage mechanics structurally shape physical safety and openability limits?

3.5. Limitations

This study is limited to the metal (tin) packaging typology; plastic, glass, or cardboard packaging are excluded from the scope. The analysis process of the research does not encompass an experimental application based on large-scale user tests; instead, it involves a structured and systematic Expert Review grounded in biomechanical models proven valid in the literature and current local anthropometric data.

3.6. Data collection and analysis

In this research, the data collection process is structured in three stages: "Theoretical Data Sources," "Physical Design Data," and "Visualization."

In the first stage (Theoretical Data Sources); the normative framework of the research was established by scanning the torque equations developed by Rowson and Yoxall (2011) and current anthropometric reference values belonging to the Turkish population (Bayraktar & Özşahin, 2018). The percentile values used in determining the design criteria were calculated according to normal distribution principles to cover 90% of the population (5th and 95th percentiles). In determining the relevant threshold values, the following formula proposed by Pheasant and Haslegrave (2006), which is accepted as a standard in the anthropometry literature, was taken as a basis:

$$p = m \pm (1.645 \times SD) \qquad (2)$$

In Equation (2), the [p] variable represents the calculated target percentile value (5th or 95th percentile); while [m] symbolizes the arithmetic mean, and [SD] represents the standard deviation of the dataset. The 1.645 coefficient used in Equation (2) is the standard z-score equivalent that covers the 90% segment of the population on the normal distribution curve and determines the extreme limits (Pheasant & Haslegrave, 2006). The values of 99.34 mm (95th percentile upper limit) and 58.02 mm (5th percentile lower limit) determined accordingly were included in the system as "theoretical decision thresholds" to audit the anthropometric compatibility of the designs. During the analysis process, referencing data from "healthy young adults," the group with the highest biomechanical capacity, ensured the adoption of the "Best-Case Scenario" approach in the study.

In the second stage (Physical Design Data); the lid diameter (r_C), grip span, and surface characteristics of the selected packaging samples were directly measured by the researcher to determine the structural parameters to be used in the theoretical comparison.

In the third stage (Visualization); representative usage scenarios were documented to concretize the dimensional incompatibilities predicted by the normative data. The usage visuals presented in the study do not aim to create an experimental dataset or perform a mechanical performance measurement. On the contrary, these visuals are technical simulations based on the visualization of geometric incompatibilities, detected through anthropometric threshold values, on a reference model.

In the analysis of the data, the descriptive analysis method, widely used in qualitative research, was preferred. This method was utilized as an analytical tool in the systematic processing of the obtained structural parameters and visual data under the three main axes (Anthropometric, Biomechanical, Safety) determined in Section 3.2. The analysis process of the research relies on a comparison model conducted over biomechanical principles and anthropometric standards in the current literature, and the theoretical inferences obtained accordingly, rather than an experimental mechanical validation (torquemeter measurement, etc.) (Baltacı, 2019). This approach aims to audit the geometric compatibility of the packaging form with the physical limits of the population on an objective plane.

3.7. Population and sample

The population of the research consists of metal (tin) packaging designs. In the sample selection process, a two-stage approach was adopted within the scope of "Purposive Sampling" strategies, which are frequently utilized for in-depth case analysis in qualitative research designs. In the first stage, the "Criterion Sampling" technique under these strategies was employed (Yağar & Dökme, 2018). This strategy is based on examining characteristic cases that meet critical importance criteria predetermined in line with the objectives of the research (Patton, 2015). Thus, it provides the researcher with the opportunity to draw the boundaries of the phenomenon to be examined deeply and clearly (Yıldırım & Şimşek, 2016). Accordingly, the initial pool was determined systematically within the framework of the "Physical Scale (Size)" and "Biomechanical Requirement (Grip Type)" criteria formulated by the researcher, rather than through a random approach.

To ensure market representation and form diversity, approximately 15 different packaging typologies were subjected to a comprehensive preliminary examination until reaching the "data saturation point" (informational redundancy)—due to their inclusion of the structural diversity of different lids, handles, and opening mechanisms specific to metal packaging (pull-ring, screw cap, wire handle, etc.) across sectors (canned food, liquid oil, and cosmetics) (Saunders et al., 2018). Three fundamental methodological criteria were used in determining the final cases from the mentioned pool. First, it was ensured that each of the three fundamental grip mechanisms (Cylindrical, Lateral, and Tip) defined by Rowson and Yoxall (2011) was represented in the sample. Second, the products were subjected to an analytical classification along the axes of "full palmar interaction" (Macro), "knuckle pressure" (Meso), and "fingertip precision" (Micro) according to the biomechanical force hierarchy they require.

In the second stage of sample selection, the "Extreme/deviant cases" strategy defined by Flyvbjerg (2006) was integrated into the process to observe the accessibility boundaries and biomechanical interactions of the designs most clearly. In this context, operational moments where the user deviates from the ideal grip form due to design constraints and most intensely needs compensatory strategies (fingernail support, hook grip, etc.) were included in the analysis as the "limit cases" of the research.

As a result of this systematic elimination process, three specific cases holistically representing different physical scales and contrasting grip requirements were determined (Figure 1). In this context, the 5L Olive Oil Tin (approx. 4.6 kg) requiring high weight management represents the Macro Scale / Cylindrical Grip; the 140g Tuna Can where finger force and wrist torque combine represents the Meso Scale / Lateral Grip; and the 10g Lip Balm Tin requiring high fingertip precision on a small surface area represents the Micro Scale / Tip Grip typologies. This selection strategy aims to thoroughly analyze the effects of common ergonomic barriers in the market on human-product interaction through the critical points where the problem is most crystallized.

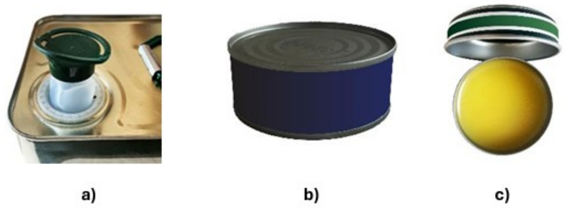


Figure 1. Classification of Metal Packaging Typologies Constituting The Research Sample According To Scale and Grip Type. (Photograph: Author).

a) Macro Scale / Cylindrical Grip (5L Tin), b) Meso Scale / Lateral Grip (140g Tuna), c) Micro Scale / Tip Grip (10g Lip Balm).

4. Results

In this section, three different metal packaging typologies selected via the purposive sampling method are analytically addressed in light of the "Reference Data Set" (Table 1), containing current measurements of the Turkish population, and the "Physical Design Parameters" of the products (Table 2). The analysis process is based on comparing the objective measurements made by the researcher with the population standards presented by Bayraktar and Özşahin (2018) on a geometric plane. The analytical evaluation of these data in terms of holistic ergonomic performance was carried out based on the statistical threshold values defined in Section 5 (See Table 3) and the biomechanical principles presented by Rowson and Yoxall (2011).

Table 1. Hand Anthropometry and Morphology Data of the Turkish Population Referenced in the Research

Variable (Measurement Parameter)	Female (Mean)	Male (Mean)
Hand Length	169.7 mm	183.9 mm
Hand Breadth	77.6 mm	87.5 mm
Hand Morphology (Shape)	*Mesocheri* (Medium)	*Brachycheri* (Short and Broad)
Krogman Hand Index	45.72	47.58

Table 1 (Reference Data Set): Source: Adapted from Bayraktar and Özşahin (2018). Furthermore, in the analyses, the biomechanical movements required to open the packaging are classified based on the grip classification defined by Rowson and Yoxall (2011) (Figure 2) and the mechanics of the ring-pull mechanism.

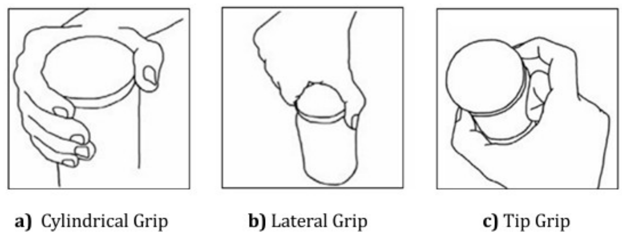


Figure 2. Fundamental Grip Types Examined Within the Scope of the Research (Adapted from Rowson and Yoxall, 2011).

In the following headings, each packaging sample is analyzed in light of the reference values in Table 1 and the biomechanical principles in Figure 1.

The critical physical measurements and structural characteristics determining the ergonomic performance of the analyzed packaging are summarized in Table 2 as a result of detailed measurements made by the researcher. All measurements are expressed in millimeters (mm) for precision and compliance with industrial standards.

Table 2. Physical Design Parameters of the Examined Metal Packaging Samples

Case No	Product Type	Relevant Grip Type	Critical Design Component	Measured Value (mm)
Case 1	5L Olive Oil Tin	Cylindrical Grip	Lid Outer Diameter	38 mm
		(Carrying)	Handle Inner Clearance Dims. (W x H)	47 mm x 34 mm
			Handle Cross-Section Thickness	5 mm

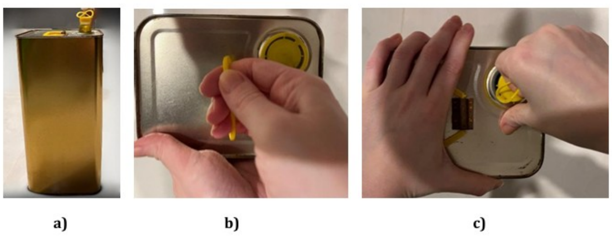
Case 2	140g Tuna Can	Lateral Grip	Ring-Pull Inner Clearance Dims. (W x H)	17 mm x 15 mm
			Ring Cross-Section Thickness	3 mm
Case 3	10g Lip Balm Tin	Tip Grip	Can Outer Diameter	45 mm
			Effective Grip Surface (Height)	8 mm

In the preceding subheadings, these raw data (product dimensions) presented in the tables were analyzed by correlating them with the reference anthropometric values in Table 1 and the grip mechanics in Figure 2. These dimensional and biomechanical data, obtained as a result of the case analyses, were analyzed and interpreted in light of the objective threshold values and "dimensional compatibility" decision criteria defined in the subsequent sections (see Section 5, Table 3).

4.1. Case 1: Macro Scale Analysis – 5L Olive Oil Tin

The 5L olive oil tin examined within the scope of Case 1 was evaluated through the "Cylindrical Grip" typology (Rowson and Yoxall, 2011). In the technical measurements conducted, the inner width of the carrying handle was documented as 47 mm, the inner handle height as 34 mm, and the cross-section thickness as 5 mm (Table 2).

When these values are compared with the average adult male hand breadth (87.5 mm) specified in the reference data set (Table 1), it was detected that the handle span offered by the product is 40.5 mm narrower than the hand breadth (Bayraktar and Özşahin, 2018). It was observed that this dimensional difference physically prevents the full placement of four fingers inside the handle and transforms the user's grip position into an asymmetric "Hook Grip" structure as seen in Figure 3b (Napier, 1956). Furthermore, the inability of the fingertip (pulp) to fully contact underneath the ring due to the narrowness of the opening ring was analyzed on a technical plane as a dimensional constraint (Figure 3c).



a) b) c)

Figure 3. Ergonomic analysis of the 5L Olive Oil tin. (Photograph: Author)

a) General form structure of the product subject to review, b) Anthropometric incompatibility caused by handle narrowness and the forced "Hook" grip, c) Access difficulty in the opening ring. (Note: The visuals are usage simulations performed with a hand structure representing the reference anthropometric measurements in Table 1.)

4.2. Case 2: Meso Scale Analysis – 140g Tuna Can

The 140g tuna can examined within the scope of Case 2 was analyzed within the framework of "Lateral Grip" biomechanics, which is established between the thumb pulp and the lateral surface of the index finger and is resorted to in actions requiring high pulling force (Rowson & Yoxall, 2011). In the measurements made, it was determined that the ring-pull has an oval inner clearance of 17 mm x 15 mm and a cross-section thickness of 3 mm (Table 2).

As documented in Figure 4a, the "zero-clearance" structure of the ring with the lid surface and the narrowness of the inner volume do not allow the fingertip of an adult with a hand morphology defined as "Brachycheiry" (Short and Broad) in Table 1 to enter the ring (Bayraktar and Özşahin, 2018). Due to this physical constraint, it was recorded in Figure 4b that the user performed the gripping action using fingernail support instead of the finger pad. The transfer of the vertical force applied during the pulling phase to the finger through a narrow surface of only 3 mm creates high pressure concentration on the tissue, leading to local deformations that challenge the biomechanical capacity; the physical manifestations of this situation are documented in Figure 4c.

a) b) c)

Figure 4. Analysis of The Opening Process of The 140g Tuna can. (Photograph: Author)

a) Access barrier caused by the ring's integrated (zero-clearance) structure with the lid surface, b) Fingernail-supported intervention to overcome the anthropometric constraint, c) High pressure concentration caused by the narrow cross-section area (3 mm) during the pulling phase. (Note: The visuals are usage simulations performed with a hand structure representing the reference anthropometric measurements in Table 1.)

4.3. Case 3: Micro Scale Analysis – 10g Lip Balm Tin

The 10g lip balm tin examined within the scope of Case 3 was evaluated through the "Tip Grip" typology, which requires the mutual coordination of the thumb and index finger tips and is generally resorted to in precision turning operations with low torque (Rowson and Yoxall, 2011).

The general form structure of the product subject to review is presented in Figure 5a. In the technical measurements conducted, the outer diameter of the lid was determined as 45 mm and the vertical lid height where the fingers will contact as 8 mm (Table 2). However, the data in Table 1 indicate that the hand structure of the Turkish population has a "short and broad" (Brachycheiry) characteristic (Bayraktar and Özşahin, 2018).

This morphological structure points out that fingertips (pulp) require a wide contact surface. However, the limited vertical surface of 8 mm offered by the product prevents the full contact of wide fingertips possessing the "Brachycheiry" typology with the surface. As a result of this incompatibility, it is analytically observed in Figure 5b that the finger tissue overflows from the lid surface and a sufficient friction area cannot be created. Surface insufficiency prevents the generation of the theoretically targeted opening torque; this situation causes the user to resort to fingernail support (leverage strategy) to compensate for the friction loss. This strategic intervention is documented within the scope of the analytical simulation in Figure 5c.

a) b) c)

Figure 5. Analysis visuals of the 10g Lip Balm tin. (Photograph: Author)

a) Anthropometric scale of the product and limited lid height, b) Overflow of finger tissue due to surface area insufficiency, c) Leverage (fingernail) strategy used to compensate for friction loss. (Note: The visuals are usage simulations performed with a hand structure representing the reference anthropometric measurements in Table 1.)

5. Discussion

In this section, the quantitative data obtained from the case analyses were evaluated along three main analysis axes in light of the statistical thresholds derived from the population standards presented by Bayraktar and Özşahin (2018) and the biomechanical principles defined in the literature.

To interpret the data presented in the Results section from an ergonomic perspective, an "Ergonomic Compatibility Decision Matrix" (Table 3) was created with technical threshold values (E) representing the extreme values of the population (95th Percentile Male and 5th Percentile Female). This matrix constitutes the objective, measurable, and methodologically delimited theoretical basis for the "incompatibility" decisions utilized during the analysis process.

Table 3. Ergonomic Compatibility Decision Matrix: Technical Thresholds and Acceptance Criteria

Analysis Axis	**Anthropometric Equivalent (Human Anatomy)**	**Examined Design Parameter**	**Reference Decision Threshold (E)**	**Gender and Percentile-Based Limit**	**Decision Criterion (Incompatibility Condition)**
5.1. Anthropometric and Geometric Compatibility	Hand Breadth	Handle / Grip Area Width	99.34 mm	Male (95th Percentile - Upper Limit)	If Dimension < E: INCOMPATIBLE
5.2. Functional and Biomechanical Interaction	Index Finger Breadth / Thickness	Ring-Pull / Clearance Gap	23.00 mm	Male (95th Percentile - Upper Limit)	If Dimension < E: INCOMPATIBLE

5.3. Safety and Inclusive Design	Hand Breadth (Palmar Grip Limit)	Lid Diameter / Grip Surface	58.02 mm	Female (5th Percentile - Lower Limit)	If Dimension < E: INCOMPATIBLE

Data Sources: The threshold values of 99.34 mm and 58.02 mm were derived from Bayraktar and Özşahin (2018) data using the method detailed in Section 3.5; the 23.00 mm value was determined as the 95th Percentile Male limit referencing Pheasant and Haslegrave (2006).

The threshold values defined in Table 3 determine the objective boundaries of the "dimensional compatibility" analysis that forms the methodological backbone of the research. In this context, the statistically derived 99.34 mm hand breadth (95th Percentile Male) and the 23.00 mm index finger thickness upper limit thresholds taken from Pheasant and Haslegrave (2006) standards were established to audit whether the physical clearances of the packaging accommodate even the broadest hand and finger morphology of the population. On the other hand, the 58.02 mm hand breadth (5th Percentile Female) lower limit threshold was included in the system as a critical reachability criterion testing the safe graspability of the packaging by users with the narrowest hand structure. The evaluations conducted in light of these objective criteria are detailed below axis by axis.

5.1. Antropometric and geometric compatibility axis

In current anthropometric studies conducted on the Turkish population, male hands are classified as "Brachycheiry" (short and broad), and female hands as "Mesocheiry" (medium) in morphological structure (Bayraktar and Özşahin, 2018). İn light of these data, it is observed that the 47 mm handle width examined within the scope of Case 1 falls below the upper threshold of 99.34 mm (95th Percentile Male) statistically derived within the scope of this study, and even below the lower threshold of 58.02 mm (5th Percentile Female). The fact that the handle span offered by the product fails to accommodate even the narrowest hand structure (5th Percentile) of the population provides analytical data indicating that the design exhibits a radical geometric incompatibility that excludes the entire adult population regardless of gender differences. The "zero-clearance" structure in Case 2 and the limited grip height of 8 mm in Case 3 constitute a dimensional barrier theoretically restricting physical access, as they fail to meet the 23.00 mm (95th Percentile Male) limit assigned as the critical threshold for fingertip access in Table 3. These findings indicate that the examined designs fail to meet even the "average user" morphometry and geometrically diverge from inclusive design principles.

5.2. Functional and biomechanical ınteraction axis

It is anticipated that the most critical biomechanical disadvantage of the analyzed metal packaging is the friction loss combined with surface area insufficiency. In the literature, it is known that the friction coefficient ($\boldsymbol{\mu}$) between the fingertip and the packaging determines grip safety; however, the natural smoothness of metal surfaces or oil contamination dramatically reduces this coefficient (Lewis et al., 2007). In light of the mentioned findings; it is theorized that the natural smoothness of the metal surface reduces friction resistance in the Case 2 (Tuna) and Case 3 (Lip Balm) samples, which fail to meet the 23.00 mm (95th Percentile Male) limit assigned as the critical threshold for fingertip access in Table 3. Biomechanically, the torque/force balance required to open a lid or carry a load is theorized by Equation (1). According to this equation, when the friction coefficient ($\boldsymbol{\mu}_{\{CH\}}$) decreases, it is anticipated as a biomechanical necessity that the user must increase the applied grip force ($\boldsymbol{N_H}$) to perform the operation (Rowson & Yoxall, 2011). In these designs falling below the grip thresholds (E) defined in Table 3, it has been evaluated as a "theoretical output"—resulting from the intersection of geometric data with biomechanical theories—that the user, unable to transmit the necessary grip force due to surface slipperiness, pushes biomechanical limits and resorts to "fingernail-supported leverage usage," which is evaluated as a "compensatory strategy" in the literature and documented in Case 2 and Case 3 visuals (Rowson and Yoxall, 2011).

5.3. Safety and ınclusive design axis

It is evaluated that the cross-sectional narrowings in the analyzed packaging harbor a structural risk in terms of user safety. Specifically, in the ring-pull analysis in Case 2, it is observed that the vertical force (F) required to open the lid is transferred to the finger through a narrow cross-sectional surface (A) of only 3 mm. According to the theoretical projection made through the equation "Pressure = Force / Surface Area" ($P = F / A$); it can be inferred that the contact surface width of the current design, when compared with the 58.02 mm (5th Percentile Female) threshold value derived within the scope of this study, exceeds the mechanical contact stress limits even for the narrowest hand structure of the population.

Formulaically, even if the applied force remains constant, the narrowing of the contact surface increases the pressure (*P*) on the soft tissue inversely (Rowson and Yoxall, 2011). The tissue deformations observed in Figure 4c and Figure 3b reflect that the design harbors critical dimensional errors not only in terms of safety but also "accessibility." The anticipation of dimensional barriers in both the female (5th Percentile) and male (95th Percentile) extreme values referenced in the analysis supports the analytical inference that the design "excludes" a large portion of the population from the design (design exclusion) (Clarkson and Coleman, 2015). More importantly, the fact that these structural barriers cannot be overcome even in the "Best-Case Scenario" based on data from "healthy young adults" with the highest biomechanical capacity concretizes that the examined packaging typologies physically narrow the boundaries of inclusive design.

6. Conclusion and Recommendations

This study has revealed the incompatibility between the superior mechanical durability of metal packaging in industrial production and the anthropometric and biomechanical limits of the human hand through an objective 'Structured Expert Review' model based on literature data. The analysis results demonstrate that the examined tin packaging designs fail to meet the anthropometric threshold values even when compared with the "Best-Case Scenario" data representing the extreme values of the population (5th Percentile Female and 95th Percentile Male). This finding theoretically proves that the "one-size-fits-all design" approach common in the metal packaging sector largely ignores local user diversity and inclusive design principles. The fact that the design challenges even the "healthy young adult" profile, considered to have the highest biomechanical capacity, objectively reveals that the packaging in question constitutes structural barriers that are difficult to overcome for disadvantaged groups such as the elderly or those with motor skill limitations, and falls outside the boundaries of inclusive design. In light of the obtained data, fundamental strategies have been developed for industrial designers and manufacturers to improve the ergonomic performance of metal packaging. Firstly, rather than universal standards in packaging dimensioning processes, it is essential to use current anthropometric datasets belonging to the local population (referenced in Table 1) as "decision thresholds"; because designs must incorporate "dimensional flexibility" to cover the 90% segment between the 5th Percentile and the 95th Percentile. Secondly, to compensate for the torque loss created by the rigid and smooth structure of the metal, it is recommended to apply micro-textures that will increase the friction coefficient (µCH) on lid surfaces, ergonomic grip zones, or dimensional optimizations suitable for the user's finger anatomy (pulp width) in handle/ring mechanisms. In conclusion, by presenting a 'Structured Expert Review' framework based on structural design parameters and anthropometric data, this study has defined the ergonomic barriers of metal packaging on a theoretical plane. In future research, it is recommended that the theoretical incompatibilities identified in this study be quantitatively verified through torquemeter-supported experimental user tests and expanded with user experience (UX) focused field research. Metal packaging design should not be considered merely an aesthetic or logistical process, but as a multidimensional area of responsibility that responds to the physical limits of human anatomy and centers on user safety and accessibility.

Conflict of Interest

No conflict of interest was declared by the authors.

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