Device to Prevent Tip-Over of Indoor Furniture

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This study proposes an innovative product design to enhance the safety of indoor furniture. Currently, furniture presents safety concerns due to various factors such as improper placement, excessive loads, and environmental influences. The most prominent of these safety issues is furniture tip-over. Therefore, product designs aimed at preventing tip-over have been developed to ensure safety in indoor environments and avert potential accidents. In the initial phase of the study, the factors contributing to tip-over in a standard cabinet were investigated: the height of force application, leg diameter, leg length, leg's position on the bottom panel, and the furniture's load status. In the second phase, designs to prevent tip-over were developed. Following prototype production stages, the developed product was mounted on the cabinet, and experiments incorporating product variables and other variations were conducted. The results indicate that the effectiveness of the developed tip-over prevention product varies depending on usage, with its impact on preventing tip-over ranging between 17.5% and 54.3%. These findings suggest that the designed product can significantly enhance indoor safety and offers a potential alternative solution for preventing furniture tip-over.

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INTRODUCTION

People spend a significant portion of their daily lives in homes, healthcare facilities, educational settings, and social spaces. The safety of furniture used in such environments is a direct factor affecting user health and safety. Furniture that does not adhere to safety standards can pose potential hazards and jeopardize users' physical well-being. In this context, choosing furniture that meets safety standards in all usage areas is crucial for ensuring individuals' quality of life and safety.

In addition to physical needs, people have safety needs and the requirement to feel secure in their living spaces. Recent studies indicate a rise in home accidents, particularly during the pandemic period. Indoor furniture plays a significant role among the causes of these accidents and injuries. Therefore, in addition to attributes affecting the functionality, comfort, easy assembly, and ergonomics, the safety factors in furniture must be prioritized and further developed (Tanure and Okimoto 2018; Balcı *et al*. 2020; Bressan *et al*. 2021; Wong *et al*. 2021).

It has been observed that a significant portion of furniture used indoors, especially bookcases, storage cabinets, dressers, *etc.*, are routinely used without any anti-tipping measures, resulting in tipping accidents causing injuries and fatalities. Particularly in spaces such as children's rooms, preschools, dormitories, and nurseries, furniture tipping due to children's unintentional actions leads to fatalities and serious injuries (Ünlü 1998;

Sato *et al*. 2006; Karbakhsh *et al*. 2008).

Another factor causing furniture to tip-over is earthquakes. Earthquakes of varying magnitudes and resulting tremors pose a threat to human life globally and within Türkiye. Although technological advancements have reduced the damage to buildings during earthquakes, indoor furniture, accessories, and other non-structural elements that can be dislodged or toppled by tremors continue to pose a risk (Winkler and Meguru 1996; Hidayet *et al*. 2017).

Non-structural interior furnishings play a significant role in potential damages arising from both human and external factors. Some studies have determined that 85% of post-earthquake damage in the United States and Japan originates from non-structural elements (Miranda and Taghavi 2003; Takahashi and Shiohara 2004; FEMA 2011).

In addition to the design and production of furniture, placement and usage within spaces is also crucial. Randomly placed furniture and fixtures can tip over or break for various reasons, hindering rescue and evacuation efforts. It should not be forgotten that the placement of interior fixtures is vital in emergencies such as earthquakes and fires (Kaneko 2012; Lu *et al.* 2020; Ferreira *et al*. 2021). Especially in earthquake-prone residential areas, indoor safety becomes critical (Aytöre 2005; Demiraslan 2005; Demirbaş 2008; Uzun *et al*. 2015; Bayraktar *et al*. 2019).

Furniture product design and development require simultaneous consideration of multiple criteria, such as functionality, practicality, aesthetics, and safety usage. Therefore, furniture design necessitates the integration of specialized scientific fields including engineering, ergonomics, and statics (Chung and Kim 2003; İmirzi 2008; Jayaram 2008; Langner and Seidel 2009; Taş 2010).

Numerous factors, from design and production to chosen accessories and end-user preferences, influence the safe usage and tipping prevention of furniture. Every year, many people are injured or killed due to furniture tipping incidents in our country and worldwide (Kalaycıoğlu *et al.* 2017; Özcan and Özcan 2023).

In the literature, furniture tipping over is seen as an important factor in accidents and injuries occurring in interior spaces (Demirel 2019). The use of furniture without taking the necessary precautions and its effect on accidents were investigated. In this study, unlike the literature, alternative solutions were focused on the prevention of tipping. For this purpose, anti-tip device options were considered to prevent negative situations such as loss of life and property, injuries, and blockage of emergency exits that may occur as a result of furniture tipping over in interior spaces.

Research on preventing furniture tipping employs various methodologies. Kalsher and Wogalter (2018) emphasize the importance of manufacturers identifying hazards and implementing design changes to increase stability, based on basic physics principles. Ogawa and Takata (2021) developed a sensing module using angular velocity sensors to detect furniture rocking motion, combining experimental data with numerical simulations to predict tipping. In the furniture manufacturing context, Carvalho and Lopes (2015) focused on improving preventive maintenance efficiency by developing standard instructions and optimizing task allocation among technicians. These diverse approaches, ranging from design modifications to sensing technologies and maintenance strategies, collectively contribute to the development of solutions for preventing furniture tipping and enhancing product safety.

Within the scope of the study, case studies were conducted regarding accidents and injuries occurring in interior spaces. It was observed that furniture tipping over is an important safety problem in interior spaces. Anti-tip design studies were conducted to solve this problem. These studies were evaluated by forming an expert commission in the field. The determined design was produced by going through revision and production stages. The product was tested by creating a tipping test device in accordance with the relevant standards.

The results obtained showed that the use of anti-tip products can prevent tipping to a great extent. Due to this product, concrete and applicable solutions are offered to create safer living spaces, prevent accidents and injuries, and increase indoor safety.

EXPERIMENTAL

Materials

In this study, 18 mm melamine-coated particleboard, compliant with the TS EN 14322 (2017) standard for furniture production, was used. The design incorporated legs of varying diameters to enhance the durability and stability of furniture elements. The performance evaluation of furniture components was conducted in accordance with national (TS EN) and international (ISO) standards. Cabinet elements were tested against forces at various heights.

Furniture Material

The 18 mm and 8 mm thick melamine-faced chipboard (MFC), produced by Kastamonu Entegre (Istanbul, Turkey), was compliant with the TS EN 14322 (2017) standard. It is commonly preferred in the market for the production of indoor furniture. Polyvinyl chloride (PVC) edge banding was used on the cabinet edges. Minifix and dowels were used as connecting elements.

Furniture Accessories

Cylindrical chrome legs, commonly used in the market, were chosen as furniture accessories. The leg height was 10 cm, and the leg diameter measurements were: 4.5 to5.5 to 6.5 cm. The leg tips were made of adjustable hard plastic.

Preparation of Experimental Samples

The dimensions of the cabinet sample prepared for the experiment were 40 x 80 x 180 (depth, width, height) cm. The 8 mm MFC was used for the back panel, minifix bolts were used as connectors, and shelf pins were used for adjustable shelves. The cabinet weight was measured as 47.5 kg.

The position of the legs was determined by referencing the corner points of the cabinet's bottom panel, ensuring equal spacing in width and depth. The legs were placed on the four corners of the bottom panel by aligning the leg centers with the intersection points of the 3.5 x 3.5 cm, 4.5 x 4.5 cm, and 5.5 x 5.5 cm distances. The experiments were conducted considering the TS 9215 (2005) and TS EN 14073-2 (2004) standards.

For the control group experiments, the cabinet was packed in two different ways: loaded and unloaded. The loads were applied homogeneously for each shelf as 1.5 kg per 1 dm^2, in accordance with the relevant standard. The used legs were applied with 3 different diameters of 4.5 to 5.5 to 6.5 cm and a height of 10 cm. Tipping values were recorded by applying force to the cabinet at 4 different heights: 100, 120, 140, and 160 cm, in accordance with the TS 9215 (2005) standard.

Anti-Tipping Product Design Studies

Within the scope of product development studies aimed at preventing furniture tip-overs, alternative anti-tipping solutions were explored. Five different anti-tipping product designs were developed within the study. The designs were evaluated based on criteria such as working principle, manufacturability, and capability to meet the demand. Following evaluations of the draft studies, the anti-tipping product model depicted in Figure 1 was determined to be the most effective solution for preventing tip-overs, and the production processes were initiated.

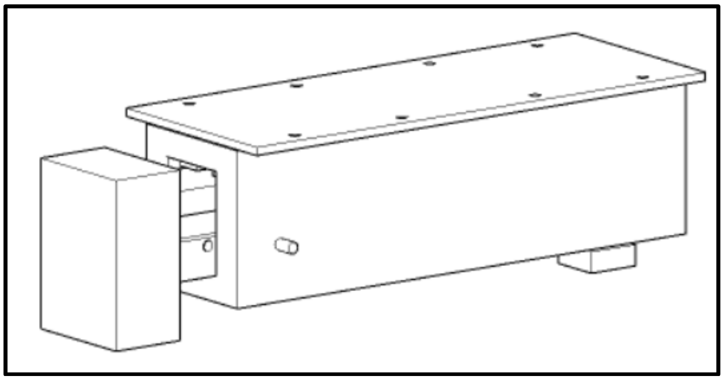

Fig. 1. General view of the anti-tipping product

Working Principle of the Designed Product

For a tipping event to occur, an external force that causes tipping must be present. When the force is increased enough to move the object, the object will move in the direction of the force, centered on the moment point. At this point, the vertical line of the object's center of gravity will shift towards the moment point, and tipping will occur when it passes this location. With the designed product, the moment point during normal use of the cabinet will be gradually shifted forward to make tipping more difficult, thus preventing or mitigating tipping to a certain extent.

When the force that causes the cabinet to tip over increases and starts to tip over, the trigger mechanism located under the product is activated and releases the support piece inside the product. The released support piece moves forward with a pusher spring mechanism. In this way, when the cabinet front legs are located, the moment point moves forward by the distance of the support piece, making tipping more difficult.

Prototype Production and Development

After the initial draft studies of the product were completed in AutoCAD, it was produced from polylactic acid (PLA) material using a 3D printer. PLA is a polyester biopolymer that can be produced from annually renewable resources such as corn, potatoes, molasses, sugarcane, and rice (Rasal *et al.* 2010; Mokhena *et al*. 2018). In addition to its environmentally friendly properties, PLA has high mechanical properties (Afrose *et al.* 2016; Bhattacharjee *et al.* 2016). The technical specifications of the PLA+ used are provided in Table 1.

Table 1. (PLA+) Technical Specifications

Material	PLA Plus
Filament Diameter	1.75 mm
Print Temperature	190-220 °C
Table Temperature	70 °C
Diameter Tolerance	±0.05 mm
Density	1.25 g/cm^3
Weight	1000 gr

The extension distance of the anti-tipping product support piece was calculated as 12 cm. This was determined by the maximum distance allowed by the height required for triggering, and the angle formed between the product and the floor. As shown in Fig. 2, the support piece was mounted to the bottom panel of the cabinet, and the support piece extension distance was implemented in increments of 4 cm, 8 cm, and 12 cm.

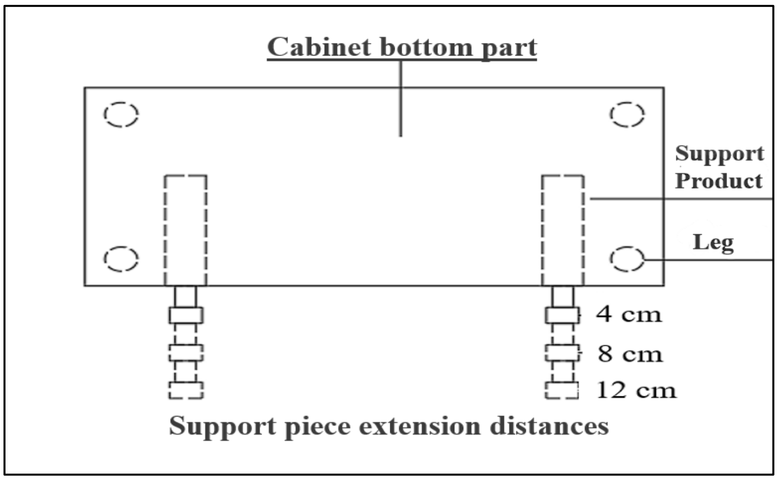

Fig. 2. Anti-tipping product support piece extension distances

Figure 2 shows the tip-over prevention product mounted on the cabinet bottom plate. The support part in the product extends forward in 3 different stages, 4 cm, 8 cm and 12 cm, depending on the user’s preference. In this way, the moment point is shifted outwards, making tipping more difficult.

Tipping Experiment Method

In the tipping experiments, the Safranbolu Şefik Yılmaz Dizdar Vocational School test laboratory and 5 KN (Kilo Newton) capacity universal testing device were utilized. The experiments were conducted in accordance with TS 9215 (2005). Holes were drilled at equal intervals on a height-adjustable pulley system, which allowed force application at different heights along the same axis. Forces were applied using a frictionless pulley system, ensuring alignment with the loading pad. The cabinet was placed on a platform fixed to the floor. Then, 3 mm high metal stop blocks were mounted on the platform to prevent the cabinet from sliding. The anti-tipping product was mounted on two edges of the cabinet's bottom shelf, as illustrated. Loads placed within the cabinet were distributed homogeneously, avoiding any support to the frame. A standardized wooden block with a 100 mm diameter and a 12 mm radius rounded front edge served as the loading pad. The stepped experimental setup is shown in Fig. 3.

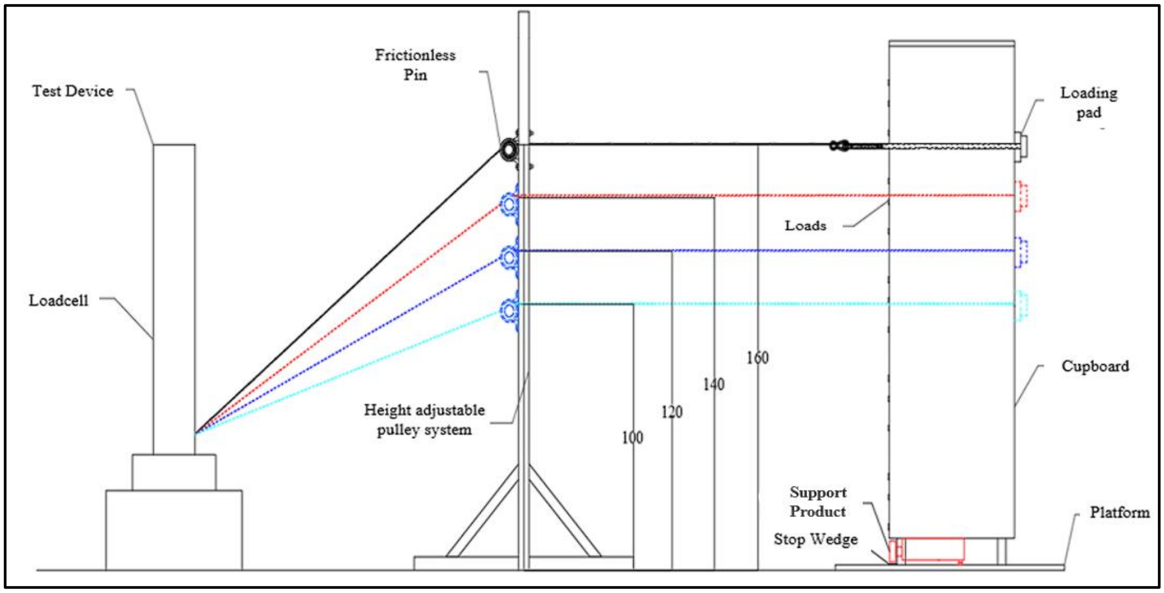

Fig. 3. Height adjustable tipping experimental setup

Statistical Procedure

This study investigated the effects of several factors on cabinet tipping, primarily the influence of the anti-tipping product, as well as the cabinet's loaded and unloaded states, the diameter of the feet, the position of the feet under the cabinet, and the height of the applied force. To determine the impact of these variables, the results obtained from the study were subjected to a multivariate analysis of variance using the SPSS statistical software package. Duncan's test was applied to indicate the level of significance when the interaction of factors was found to be significant at a 5% error rate. Results were evaluated at a 95% confidence interval with a significant level of $p<0.05$.

RESULTS AND DISCUSSION

This phase investigated the effects of the designed anti-tipping product. Each stage of the experimental tests was conducted in accordance with national and international standards, and the findings are presented below.

Measurements were taken on the cabinet, which had an unloaded weight of 47.5 kg, using the prepared experimental setup. The mean tipping values and standard deviations obtained from these measurements are presented in Table 2. The variables influencing these mean values, including the cabinet's loaded and unloaded states, the positions of the feet on the bottom shelf, the height of the applied force, and the foot diameter, are included in the table.

Examining the mean values in Table 2, the smallest mean value for the unloaded cabinet was 63.94 N, observed with a 4.5 cm foot diameter at the 5.5 cm x 5.5 cm foot position in the control measurement. The largest mean value was 166.7 N, which was observed with a 6.5 cm foot diameter, a 12 cm product support piece length, at the 3.5 cm x 3.5 cm foot position. The analysis of variance for the aforementioned variables, evaluated at a significance level of $p<0.05$, is presented in Table 4, along with the mean values for the loaded cabinet. The mean values for the loaded cabinet with the anti-tipping product are provided in Table 3.

In Table 3, the smallest mean value for the unloaded cabinet was 247.4 N, observed with a 4.5 cm foot diameter at the 5.5 cm x 5.5 cm foot position in the control measurement. The largest mean value was 560.4 N, observed with a 6.5 cm foot diameter, a 12 cm product support piece length, at the 3.5 cm x 3.5 cm foot position. The analysis of variance for the aforementioned variables, evaluated at a significance level of $p<0.05$, is presented in Table 4, alongside the mean values for the unloaded cabinet.

Table 2. Average Values (N) Of Unloaded Cabinet with Anti-Tip Device

			Force Application Height							
			100 cm		120 cm		140 cm		160 cm	
Product Support Length	Foot Diameter	Foot Position	Mean	S.d	Mean	S.d	Mean	S.d	Mean	S.d
(cm)	(cm)	(cm)	(N)		(N)		(N)		(N)	
4	4.5	3.5 x 3.5	128.52	0.82	104.23	0.54	95.01	0.51	83.05	0.63
		4.5 x 4.5	129.34	1.30	104.34	0.36	95.20	0.59	80.71	1.02
		5.5 x 5.5	128.19	2.35	103.14	1.45	95.56	1.81	80.89	1.80
	5.5	3.5 x 3.5	128.83	1.19	104.55	0.87	96.98	0.69	82.82	1.41
		4.5 x 4.5	129.01	0.94	103.63	0.48	97.23	0.42	82.06	1.94
		5.5 x 5.5	127.09	1.98	103.94	1.17	94.56	1.09	81.23	1.49
	6.5	3.5 x 3.5	128.08	2.46	105.16	0.76	97.49	0.74	83.36	1.81
		4.5 x 4.5	129.39	2.22	104.11	1.31	95.27	0.83	81.48	2.34
		5.5 x 5.5	127.28	0.71	105.07	0.74	96.13	1.14	80.97	1.30
8	4.5	3.5 x 3.5	143.62	0.57	114.56	0.85	106.46	0.66	89.45	0.64
		4.5 x 4.5	143.28	1.22	115.34	0.72	107.03	0.57	90.28	1.44
		5.5 x 5.5	144.40	2.17	114.77	1.81	105.10	0.94	90.11	1.92
	5.5	3.5 x 3.5	144.29	1.08	114.80	0.59	106.72	0.54	90.01	0.84
		4.5 x 4.5	144.68	1.41	113.73	0.59	106.81	0.41	90.49	0.97
		5.5 x 5.5	145.46	1.19	113.82	1.08	106.22	0.73	91.05	1.47
	6.5	3.5 x 3.5	145.43	1.93	115.97	0.83	107.56	0.92	91.12	2.01
		4.5 x 4.5	143.09	0.56	116.12	0.48	107.22	0.90	91.07	1.23
		5.5 x 5.5	143.57	0.81	114.18	0.83	106.09	0.73	90.64	1.57
12	4.5	3.5 x 3.5	165.11	0.89	129.22	0.52	116.63	0.81	102.17	1.54
		4.5 x 4.5	165.55	0.92	129.03	0.74	117.03	1.19	102.16	1.55
		5.5 x 5.5	163.87	1.66	127.48	1.39	115.20	1.36	101.21	2.45
	5.5	3.5 x 3.5	164.23	0.91	129.85	0.96	117.86	1.01	101.99	1.13
		4.5 x 4.5	164.73	0.74	129.20	0.24	115.49	0.86	102.27	1.11
		5.5 x 5.5	164.6	1.27	128.90	1.16	117.44	1.39	102.44	0.88
	6.5	3.5 x 3.5	166.77	0.77	130.28	1.48	118.51	0.70	102.88	1.44
		4.5 x 4.5	165.75	1.33	128.89	0.78	116.16	0.65	101.85	1.41
		5.5 x 5.5	163.73	0.69	128.24	0.75	116.18	1.41	101.15	2.23
CONTROL	4.5	3.5 x 3.5	108.75	0.90	86.96	0.94	78.29	0.59	68.80	0.45
		4.5 x 4.5	102.66	0.84	79.77	0.55	76.14	0.39	66.28	0.45
		5.5 x 5.5	96.06	1.02	75.30	0.72	70.74	0.39	63.94	0.79
	5.5	3.5 x 3.5	115.71	0.94	89.79	1.58	82.94	0.62	70.77	0.30
		4.5 x 4.5	107.01	0.59	83.49	0.49	76.38	0.41	67.76	0.66
		5.5 x 5.5	100.54	1.01	77.47	0.52	73.96	0.98	64.87	1.13
	6.5	3.5 x 3.5	120.75	2.54	94.97	1.02	84.08	0.49	72.33	0.41
		4.5 x 4.5	108.39	0.88	85.70	0.84	77.57	0.47	68.27	0.49
		5.5 x 5.5	102.32	0.99	79.52	0.77	75.88	0.79	65.74	0.23

Table 3. Average Values of Loaded Cabinet with Anti-Tip Device

			Force Application Height							
			100 cm		120 cm		140 cm		160 cm	
Support Piece Length	Foot diameter	Foot condition	Mean	S.d	Mean	S.d	Mean	S.d	Mean	S.d
(cm)	(cm)	(cm)	(N)		(N)		(N)		(N)	
4	4.5	3.5 x 3.5	494.14	1.12	414.61	0.65	379.69	1.53	319.93	1.26
		4.5 x 4.5	491.08	1.56	415.3	0.41	379.31	2.08	318.46	1.26
		5.5 x 5.5	491.02	1.28	413.5	0.56	378.5	3.7	318.93	2.1
	5.5	3.5 x 3.5	493.01	1.32	416.08	0.45	383.12	2.4	319.54	1.46
		4.5 x 4.5	492.53	0.79	415.65	0.63	379.63	1.4	319.39	1.84
		5.5 x 5.5	492.41	1.07	414.91	0.75	379.12	4.13	319.48	1.47
	6.5	3.5 x 3.5	493.26	1.52	416.2	0.73	382.54	2.81	320.13	2.45
		4.5 x 4.5	492.16	0.92	414.13	1.18	380.22	2.07	320.03	1.39
		5.5 x 5.5	491.95	1.74	414.08	0.89	380	3.3	320.12	1.45
8	4.5	3.5 x 3.5	519.86	0.82	443.89	1.07	406.13	2.27	341.17	1.52
		4.5 x 4.5	520.9	2.75	442.06	0.5	405.71	1.87	341.11	1.6
		5.5 x 5.5	519.48	2.28	445.15	2.37	406.34	2.87	340.54	2.75
	5.5	3.5 x 3.5	521.56	1.64	444.53	0.64	408	1.04	340.55	1.55
		4.5 x 4.5	519.41	0.65	443.97	1.25	406.14	1.43	340.47	1.54
		5.5 x 5.5	519.34	1.65	445.48	0.9	407.15	1.35	341.66	2.61
	6.5	3.5 x 3.5	523.15	1.37	447.19	1.74	408.35	1.28	341.46	2.1
		4.5 x 4.5	523.56	1.13	445.05	1.19	407.09	1.18	341.15	1.57
		5.5 x 5.5	522.3	2.18	442.9	1.87	405.4	2.06	339.99	2.4
12	4.5	3.5 x 3.5	558.09	2.21	474.37	1.61	437.09	0.93	361.79	1.73
		4.5 x 4.5	554.52	0.98	476.66	2.16	436.91	1.4	360.73	2.51
		5.5 x 5.5	557.71	4.36	471.63	2.32	434.05	3.07	360.65	2.57
	5.5	3.5 x 3.5	559.42	1.48	475.33	1.15	436.51	1.05	362.62	1.99
		4.5 x 4.5	554	1.64	476.97	1.1	437.91	1.15	361.66	2.86
		5.5 x 5.5	556.72	2.34	474.9	1.03	437.95	2.24	362.23	1.98
	6.5	3.5 x 3.5	560.42	1.18	477.38	1.63	438.45	2.39	363.82	2.07
		4.5 x 4.5	556	2.18	476.86	1.22	436.14	2.81	359.81	1.23
		5.5 x 5.5	554.3	4.32	475.47	0.66	436.03	1.11	361.1	2.39
CONTROL	4.5	3.5 x 3.5	427.6	1.69	355.52	0.94	330.95	1.83	278.02	0.84
		4.5 x 4.5	406.94	1.18	338.67	1.57	311.86	3.71	267.67	0.47
		5.5 x 5.5	370.55	1.16	322.29	1.7	295.36	0.84	247.4	0.86
	5.5	3.5 x 3.5	442.21	2.11	365.51	3.48	345.24	3.1	283.39	0.53
		4.5 x 4.5	415.41	1.23	344.33	1.99	321.2	1.95	269.96	1.24
		5.5 x 5.5	395.82	1.28	330.13	1.65	298.89	0.88	259.93	1.27
	6.5	3.5 x 3.5	450.56	3.33	375.34	4.83	357.9	1.23	296.59	2.77
		4.5 x 4.5	426.64	1.22	353.47	2.47	329.55	5.32	276.65	2.77
		5.5 x 5.5	407.76	0.99	337.66	0.76	309.07	3.04	268.46	0.84

Table 4. Multivariate Analysis of Variance Results for Loaded and Unloaded Mean Data (N)

Sources of Variation	Sum of Squares	Degrees of Freedom	Mean Square Value	F	Significance Level
Corrected Model	37036997.71a	287	129048.77	49757.19	0.000
Constant Term	95084099.6	1	95084099.6	36661467.8	0.000
A	32310708.7	1	32310708.7	12458003.1	0.000
B	2350459.39	3	783486.46	302087.98	0.000
C	1287168.54	3	429056.18	165430.7	0.000
D	3291.55	2	1645.77	634.56	0.000
E	12015.43	2	6007.71	2316.39	0.000
A * B	702955.35	3	234318.45	90345.9	0.000
A * C	275670.14	3	91890.05	35429.94	0.000
A * D	971.97	2	485.99	187.38	0.000
A * E	3294.07	2	1647.03	635.05	0.000
B * C	35759.21	9	3973.25	1531.96	0.000
B * D	144.34	6	24.06	9.28	0.000
B * E	585.13	6	97.52	37.6	0.000
C * D	6132.53	6	1022.09	394.09	0.000
C * E	25019.59	6	4169.93	1607.8	0.000
D * E	223.92	4	55.98	21.59	0.000
A * B * C	7419.59	9	824.4	317.86	0.000
A * B * D	53.82	6	8.97	3.46	0.002
A * B * E	207.47	6	34.58	13.33	0.000
A * C * D	2240.35	6	373.39	143.97	0.000
A * C * E	8610.74	6	1435.12	553.34	0.000
A * D * E	25.92	4	6.48	2.5	0.041
B * C * D	524.67	18	29.15	11.24	0.000
B * C * E	1356.22	18	75.35	29.05	0.000
B * D * E	85.42	12	7.12	2.75	0.001
C * D * E	228.38	12	19.03	7.34	0.000
A * B * C * D	190.69	18	10.59	4.09	0.000
A * B * C * E	574.43	18	31.91	12.31	0.000
A * B * D * E	148.31	12	12.36	4.77	0.000
A * C * D * E	101.94	12	8.5	3.28	0.000
B * C * D * E	362.51	36	10.07	3.88	0.000
A * B * C * D * E	467.4	36	12.98	5.01	0.000
A: Load Status B: Force Application Height C: Support Piece Length D: Foot Diameter E: Foot Position					

According to the multivariate analysis of variance results presented in Table 4, the variables of loaded and unloaded cabinet states, foot positions on the bottom shelf, applied force height, support piece length, and foot diameter were individually found to have significant effects on tipping. Furthermore, their two-way, three-way, four-way, and five-way interactions were also found to be significant among themselves. The Duncan test results regarding the effect of the applied force height on the tipping of the cabinet with the product are provided in Table 5.

Table 5. Duncan Test Results for the Effect of Force Height on Tipping (N)

Height (cm)	Average (N)	Homogeneity Group
100	316.33	A
120	264.20	B
140	242.82	C
160	204.51	D

A statistical comparison of the effect of the force application height on the tipping values of the product cabinet revealed a statistical difference between all force application heights. Furthermore, it was observed that the average tipping value decreased as the force application height increased. The Duncan test results regarding the effect of the anti-tipping product support piece length used in the cabinet on tipping are shown in Table 6.

Table 6. Duncan Test Results of the Effect of the Support Piece Length on Tipping (N)

Support Piece Length (cm)	Average (N)	Homogeneity Group
Control	211.59	A
4	252.20	B
8	271.15	C
12	292.92	D

A comparison of the effect of the anti-tipping product support piece lengths used in the cabinet on the tipping values revealed a statistical difference between the control group (with the product closed) mean values and the 4, 8, and 12 cm support piece extension distances. It was also determined that the average tipping values increased as the support piece extension distance increased. The Duncan test results regarding the effect of the leg diameters used in the cabinet with the anti-tipping product on tipping are shown in Table 7.

Table 7. Duncan Test Results of the Effect of Leg Diameters on Tipping (N)

Diameter (cm)	Average (N)	Homogeneity Group
4.5	255.05	A
5.5	257.10	B
6.5	258.75	C

A comparison of the effect of the leg diameters used in the cabinet with the product on the tipping values showed a statistical difference between all leg diameters. Furthermore, it was observed that the average tipping values for the leg diameters were very close to each other. The Duncan test results regarding the effect of the positions of the legs used in the cabinet on the bottom shelf on tipping are shown in Table 8.

Table 8. Duncan Test Results of the Effect of Leg Locations on Tipping (N)

Locations (cm)	Average (N)	Homogeneity Group
5.5 x 5.5	253.56	C
4.5 x 4.5	256.70	B
3.5 x 3.5	260.63	A

A comparison of the effect of the positions of the legs used in the cabinet on tipping revealed a statistical difference between all leg positions. The Duncan test results regarding the effect of the cabinet's load status on tipping are shown in Table 9.

Table 9. Duncan Test Results of the Effect of Cabinet Load Status on Tipping (N)

Load Status	Average (N)	Homogeneity Group
Unloaded	114.93	A
Loaded	429.25	B

A comparison of the effect of whether the cabinet with the product was loaded or unloaded on the average tipping values revealed a statistical difference between the load statuses. The product's support piece extension distance and the applied tipping forces demonstrated a tipping prevention effect in all variations tested on both unloaded and loaded cabinets. These effects are shown in Fig. 4.

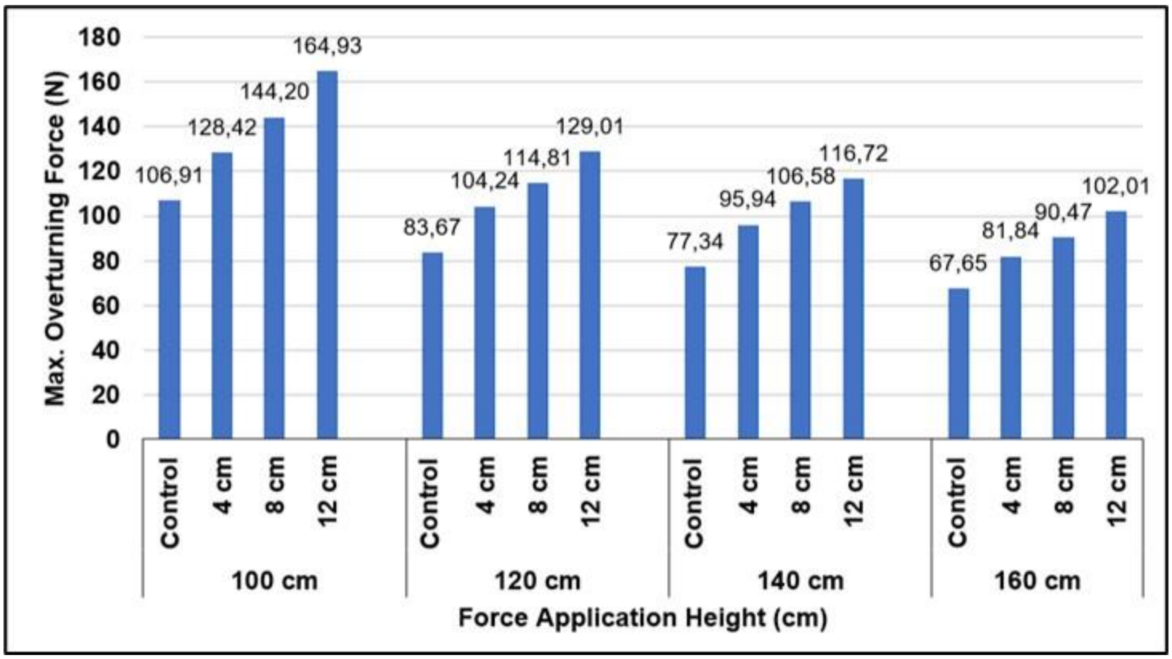

Fig. 4. Product effect at different force application values in unloaded cabinet (N)

When examining the product's effects at different heights between unloaded cabinets with and without the anti-tipping product, the lowest value was found to be 20.12% at a force application height of 100 cm and a support piece extension distance of 4 cm, while the greatest anti-tipping product effect was 54.27% at a force application height of 100 cm and a support piece extension distance of 12 cm.

The anti-tipping product's support piece extension distance and the tipping forces applied at different heights demonstrated a tipping prevention effect in all variations tested on the loaded cabinet. These effects are shown in Fig. 5.

When examining the product's effects at different heights between loaded cabinets with and without the anti-tipping product, the lowest value was found to be 17.48% at a force application height of 160 cm and a support piece extension distance of 4 cm, while the greatest product effect was 37.04% at a force application height of 120 cm and a support piece extension distance of 12 cm.

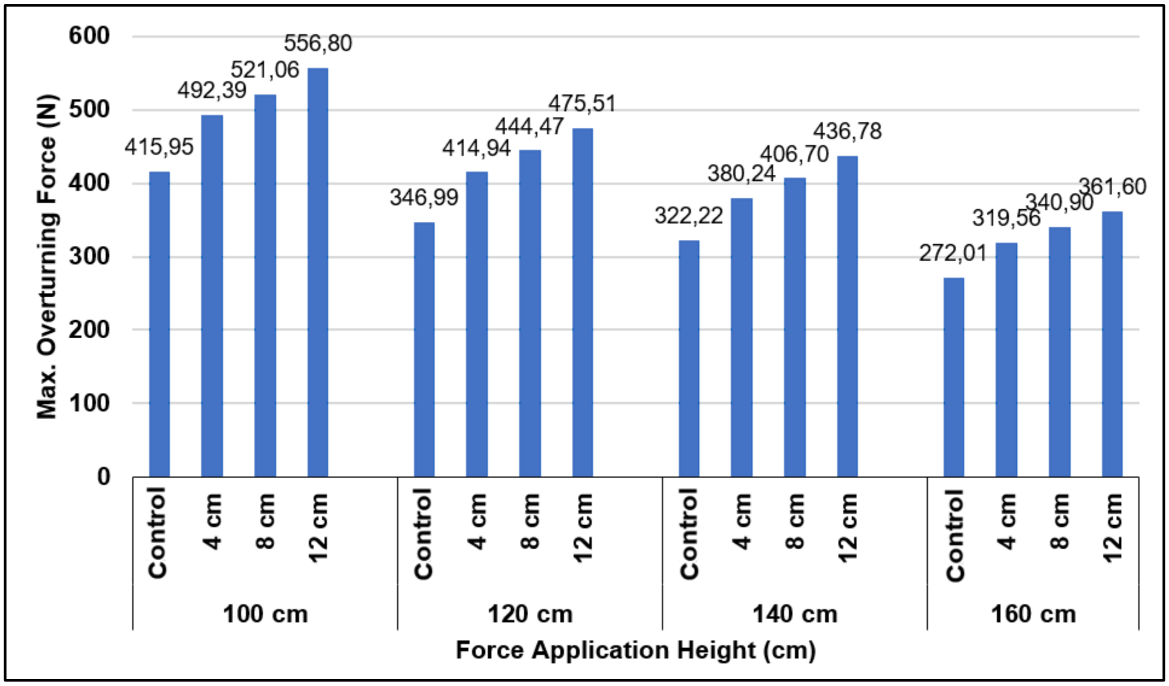

Fig. 5. Product effect at different force application values in loaded cabinet (N)

CONCLUSIONS

1. When comparing the effects of the anti-tipping product in loaded and unloaded cabinet conditions, it was found that the anti-tipping product provided a 37.39% increase in the average values encompassing all tipping variables for the unloaded cabinet, while the corresponding value was 27.01% for the loaded cabinet. It was observed that the anti-tipping product increased environmental safety by making tipping more difficult in both load conditions.
2. When comparing the effectiveness of the anti-tip device across all leg diameters used in cabinets, it was observed that the device made tipping more difficult by 24.4% for 4.5 cm leg diameters, 21.9% for 5.5 cm leg diameters, and 19.5% for 6.5 cm leg diameters. It also reduced the effect of leg diameter on tipping, resulting in average values between 255 N and 259 N. It was observed that the anti-tip device improved environmental safety by making tipping more difficult across all leg diameters.
3. When comparing the effect of the anti-tip device on tipping across different leg mounting positions, the product increased the resistance to tipping by 13.6% for the 3.5 cm x 3.5 cm leg position, 21.9% for the 4.5 cm x 4.5 cm position, and 31.2% for the 5.5 cm x 5.5 cm position. It mitigated the influence of leg position on tipping and enhanced overall safety by increasing tip resistance across all leg diameters.
4. Examining the impact of the anti-tip device on mean force application heights shows the device consistently increased tipping resistance. This improvement was observed at levels of 22.06% at 100 cm, 23.43% at 120 cm, 22.5% at 140 cm, and 19.02% at 160 cm. The anti-tip device effectively made tipping more difficult across all force application heights.

5. Utilizing the product's support piece at its maximum extension (12 cm for this product) increased the force required for tipping by 29.9%, thus making tipping more difficult. For optimal tip prevention, the maximum support piece extension is recommended.
6. The developed product eliminates the need for drilling into walls or fixing furniture to any specific location within the interior space. Furniture equipped with the anti-tip device can be moved and used anywhere within the space as desired. This allows for the safe implementation of alternative interior design options.
7. The product was assembled for experimental use. It is possible to produce and develop the product from shock absorbing materials or in different forms so that it does not harm the user who may be there when the support part of the product comes forward. The product working logic is consistent with the current laws of physics. Various variations can be made by developing the product with different simulations and examples.
8. This product provides a visually appealing alternative to traditional wall-mounted cabinet hardware. Instead of unsightly mounting brackets on or beside the cabinet, this product is placed underneath, preserving the aesthetics while ensuring a safer and more decorative environment.
9. It was observed that the anti-tip device can increase the resistance to tipping of furniture during light to moderate earthquakes by up to 54%, mitigating the effects of horizontal seismic forces. This suggests potential use as an alternative solution to prevent injuries caused by furniture tipping during earthquakes.

REFERENCES CITED

Afrose, M. F., Masood, S. H., Iovenitti, P., Nikzad, M., and Sbarski, I. (2016). "Effects of part build orientations on fatigue behaviour of FDM-processed PLA material," *Progress in Additive Manufacturing* 1(2), 21-28. DOI: 10.1007/s40964-015-0002-3

Aytöre, O. S. (2005). "Effects of mass-produced furniture on humans during earthquakes in terms of storage and production methods," in: *Earthquake Symposium*, pp. 1251-1260.

Balcı, E., Sezer, L., and Durmuş, H. (2020). "Increase in home accidents in children during the Corona days," *Turkish Journal of Pediatrics* 14, 458-459.

Bayraktar, H., Sahtiyancı, E., and Kuru, A. (2019). "Determining the potential effects of non-structural risks caused by earthquakes in schools using the risk assessment matrix method," *Disaster and Risk Journal* 2(2), 128-152.

Bhattacharjee, N., Urrios, A., Kang, S., and Folch, A. (2016). The upcoming 3D printing revolution in microfluidics," *Lab on a Chip* 16(10), 1720-1742. DOI: 10.1039/C6LC00163G

Bressan, S., Gallo, E., Tirelli, F., Gregori, D., and Da Dalt, L. (2021). "Lockdown: More domestic accidents than COVID-19 in children," *Archives of Disease in Childhood* 106(2). DOI: 10.1136/archdischild-2020-319547

Carvalho, B., and Lopes, I. (2015). "Preventive maintenance development: A case study in a furniture company," World Congress on Engineering.

Chung, S., and Kim, G. M. (2003). "Performance effects of partnership between manufacturers and suppliers for new product development: The supplier's standpoint," *Research Policy* 32, 587-603. DOI: 10.1016/S0048-7333(02)00047-1

Demirarslan, D. (2005). "Examination of housing and furniture usage habits in terms of seismicity in Turkish and Japanese residential interiors," in: *Earthquake Symposium*, pp. 728-737.

Demirbaş, Ç. (2008). *Security Analysis and Solution Proposals for Interiors of Residences in Earthquake Zones*, Undergraduate Thesis, Karadeniz Technical University, Trabzon.

Demirel, C. A. (2019). *Investigation of the Effects of Furniture Accessories on Furniture Design in the Context of Turkey*, Master's Thesis, Mimar Sinan Fine Arts University, Istanbul.

Federal Emergency Management Agency (FEMA). (2011). *Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide*, Washington, D. C.

Ferreira, M., Azzaro, R., Musacchio, G., Rupakhety, R., Bessason, B., Thorvaldsdottir, S., Lopes, M., Oliveira, C. S., and Solarino, S. (2021). "What scientific information on non-structural elements seismic risk people need to know? Part 1: Compiling an inventory on damage to non-structural elements," *Annals of Geophysics* 64(3), p. SE321. DOI: 10.4401/ag-8412

Hidayetoğlu, L. M., and Yıldırım, K. (2017). "Innovative approaches in furniture assembly and sustainability in design," *Advanced Technology Sciences Journal* 6, 122-132.

İmirzi, H. Ö. (2008). *Strength Properties of Box-Type Furniture Produced with Different Construction Techniques and Boards of Varying Thicknesses*, Ph.D. Dissertation, Gazi University Institute of Science, Ankara.

Jayaram, J. (2008). "Supplier involvement in new product development projects: Dimensionality and contingency effects," *International Journal of Production Research* 46(13), 3717-3735. DOI: 10.1080/00207540600787010

Kalaycıoğlu, H., Aras, U., and Çınar, T. (2017). "Complementary elements in furniture 'accessories'," *Advanced Technology Sciences Journal* 6(3).

Kaneko, M. (2012). "Fixing and layout of furniture and fixtures," in: *Earthquake-resistant Building Design for Architects*, Japan Institute of Architects (JIA) and Japan Aseismic Safety Organization (JASO), Tokyo.

Kalsher, M., and Wogalter, M.S. (2018). Chapter: Not a Step! Forensic Human Factors and Ergonomics , CRC Press,18 pages. DOI: 10.1201/9780429462269-7

Karbakhsh, M., Zargar, M., Zarei, M. R., and Khaji, A. (2008). "Childhood injuries in Tehran: A review of 1281 cases," *Turkish Journal of Pediatrics* 50(4).

Langner, B., and Seidel, V. P. (2009). "Collaborative concept development using supplier competitions: Insights from the automotive industry," *Journal of Engineering Technology and Management* 26, 1-14. DOI: 10.1016/j.jengtecman.2009.03.007

Lu, X., Yang, Z., Xu, Z., and Xiong, C. (2020). "Scenario simulation of indoor post-earthquake fire rescue based on building information model and virtual reality," *Advances in Engineering Software* 143, article 102792. DOI: 10.1016/j.advengsoft.2020.102792

Miranda, E., and Taghavi, S. (2003). "Estimation of seismic demands on acceleration-sensitive nonstructural components in critical facilities," in: *Proceedings of the Seminar on Seismic Design, Performance and Retrofit of Nonstructural Components in Critical Facilities*, Newport Beach, CA, USA, pp. 347-360.

Mokhena, T. C., Sefadi, J. S., Sadiku, E. R., John, M. J., Mochane, M. J., and Mtibe, A. (2018). "Thermoplastic processing of PLA/cellulose nanomaterials composites,"

Polymers 10(12), article 1363. DOI: 10.3390/polym10121363
Ogawa, T., and Takata, S. (2021). "Aimed to generate a dynamic indoor risk map Development of furniture rocking vibration module," The Proceedings of the Symposium on Evaluation and Diagnosis.
Özcan, S., and Özcan, C. (2023). "The effect of accessories used in interior furniture on increasing safety and preventing overturning," *Kastamonu University Journal of Forestry Faculty* 23(1), 22-30. DOI: 10.17475/kastorman.1269480
Rasal, R. M., Janorkar, A. V., and Hirt, D. E. (2010). "Polylactic acid modifications," *Progress in Polymer Science* 35(3), 338-356. DOI: 10.1016/j.progpolymsci.2009.12.003
Sato, T., Motosaka, M., and Mano, A. (2006). "Investigation of human injuries during the July 26, 2003 Northern Miyagi Earthquake with focus on furniture overturning," *Journal of Natural Disaster Science* 28(1), 15-24.
Takahashi, N., and Shiohara, H. (2004). "Life cycle economic loss due to seismic damage of nonstructural elements," in: *Proceedings of the 13th World Conference on Earthquake Engineering*, Vancouver, BC, Canada, pp. 203-204.
Tanure, R. L. Z., and Okimoto, M. (2018). "Requirements' literature review for the development of furniture for people with motor impairments," *Advances in Intelligent Systems and Computing* 588, 541-548. DOI: 10.1007/978-3-319-60582-1_54
Taş, H. H. (2010). *Investigation of the Earthquake Behavior of Non-structural Industrial Wood Interior Equipment*, Master's Thesis, Süleyman Demirel University Institute of Science, Isparta.
TS 9215 (2005). "Wooden furniture – Strength and stability tests," Turkish Standards Institute (TSE), Ankara.
TS EN 14073-2 (2004). "Office furniture – Test methods for determining the strength and stability of storage furniture frames," Turkish Standards Institute (TSE), Ankara.
TS EN 14322 (2017). "Wood-based panels – Melamine-faced panels for interior uses – Definitions, requirements and classification," Turkish Standards Institute (TSE), Ankara.
Ünlü, F. (1998). *An Approach to the Interaction of Space-Human Behavior in the Formation and Shaping of Interior Spaces*, Master's Thesis, Hacettepe University Institute of Social Sciences, Ankara.
Uzun, O., Percin, O., and Küreli, İ. (2015). "Determination of earthquake preparedness furniture and interiors (Simav and Duzce case)," *Kastamonu University Journal of Forestry Faculty* 15(2), article 07535. DOI: 10.17475/kuofd.07535
Winkler, T., and Meguro, K. (1996). "Response of interior rigid body assemblies to dynamic excitation," in: *Proceedings of the Eleventh World Conference on Earthquake Engineering*, Mexico City, Mexico, pp. 581.
Wong, T. W. K., Hung, J. W. S., and Leung, M. W. Y. (2021). "Pediatric domestic accidents during COVID-19 pandemic in Hong Kong," *Surgical Practice* 25, 32-37. DOI: 10.1111/1744-1633.12477

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