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The Effect of Wok Size and Handle Angle on the Maximum Acceptable Weights of Wok Flipping by Male Cooks

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Abstract: A wok with a straight handle is one of the most common cooking utensils in the Asian kitchen. This common cooking instrument has seldom been examined by ergonomists. This research used a two-factor randomized complete block design to investigate the effects of wok size (with three diameters – 36 cm, 39 cm and 42 cm) and handle angle (25°, 10°, –5°, –20°, and –35°) on the task of flipping. The measurement criteria included the maximum acceptable weight of wok flipping (MAWF), the subjective rating and the subjective ranking. Twelve experienced males volunteered to take part in this study. The results showed that both the wok size and handle angle had a significant effect on the MAWF, the subjective rating and the subjective ranking. Additionally, there is a size-weight illusion associated with flipping tasks. In general, a small wok (36 cm diameter) with an ergonomically bent handle (–20° ± 15°) is the optimal design, for male cooks, for the purposes of flipping.

Key words: Food industry, Cooking, Cooking utensils, Psychophysics

Introduction

Work-related musculoskeletal disorders (WMSDs) are very common amongst cooks in the catering industry. In a survey of 471 kitchen cooks, the Occupational Safety and Health Council of HongKong[1)] found that the most common work-related disorder was musculoskeletal disorders, with about 41.2% of cooks suffering from musculoskeletal disorders, in the past 12 months. Gigstad[2)] confirmed that 57% of the cooks reported pain in their hands and wrists. Chyuan *et al*.[3)] found that 84% of participants reported a WMSD in the previous month, with a high prevalence of shoulder (58%), neck (54%), lower back/waist (53%) and finger/waist (46.5%) disorders, among hotel restaurant workers in Taiwan. Similarly, Chyuan[4)] also reported a high prevalence of WMSDs for the shoulder (41.1%), hands/wrists (38.2%) and lower back (40.1%), among foodservice workers in Taiwan.

In Asian countries, the straight-handled wok is one of the most indispensable cooking utensils. In the production of stir-fry dishes, such as fried chicken cubes, the quicker the food is evenly stirred and heated in the wok, the more flavorful is the finished product. However, when one uses a straight-handled wok for flipping, the repeated action of swinging the wok up and down, to quickly stir the food in the wok, involves extensive arm and wrist movement, especially dorsi flexion, palmar flexion and wrist radial and ulnar deviation. This non-neutral posture, accompanied by high torque and a high rate of repetition is very apt to cause cumulative trauma disorder (CTDs) injuries in the user's upper extremity[5–9)].

Werner *et al*.[10)] indicated that one of the most impor-

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tant factors in hand tool design is the avoidance of wrist deviation and flexion. Armstrong and Chaffin[11] confirmed that flexion and extension of the wrist were associated with a high incidence of carpal tunnel syndrome. Tanaka *et al.*[12] found that radial and ulnar deviations are also implicated in carpal tunnel syndrome. From a biomechanical viewpoint, Tichauer and Gage[13] suggested the ergonomics principle which states, "It is better to bend the tool and not the wrist". Emanuel *et al.*[14] recommended that, "the handles of all tools and sports apparatuses should be bent at 19° ± 5°", and applied for a patent for this idea.

The bent electric soldering iron, designed by Tichauer[15], was the first bent handle design that successfully reduced the deviation and flexion and pressure imposed on the wrist. From then on, bent handle designs have been widely used in hand tools. As mentioned by Leamon and Dempsey[5], bent-handled tools have been widely advocated, in ergonomics literature, to control exposure to deviated wrist position and subsequent cumulative trauma disease[15–22]. After observing the flipping, behavior of cooks in Chinese kitchens, this study found that the cooks customarily used the wrist of the nondominant hand as a fulcrum, to allow them to swing the wok up and down, quickly. These movements impose heavy physical demands and biomechanical stresses upon the upper limbs of the cooks. However, the idea of a traditional wok with a bent handle has never been explored by ergonomists.

Another potential hazard in wok flipping is the size-weight illusion that occurs while holding and lifting a heavy object, by wrist flexion. In other words, the cooks may perceive larger woks to be lighter than smaller woks of the same mass[25]. If this illusion occurs in wok flipping, a larger wok could lead to cooks lifting a greater weight and exceeding their lifting capacity[26]. However, information as to how the size of the wok affects size-weight illusion and flipping capability is still insufficient. Therefore, an exploration of the influence of the handle angle and wok size on flipping capability is very important. This study investigates whether smaller woks, with bent handles decrease subjective fatigue and discomfort and reduce the risk of occupational injury, for cooks.

Methods

Subjects

Twelve paid volunteers, each with at least one year of cooking experience, were recruited for this study. The dominant hand of each subject was the right hand. The average age, height and weight were 21.3 yr (SD=1.56 yr), 168.48 cm (SD=4.26 cm) and 68.71 kg (SD=10.52 kg), respectively. Once the subjects were determined to have no musculoskeletal injuries, nor any cardiovascular diseases, or disorders, they were asked to sign an informed consent form. Each subject was told not to eat, smoke, or drink alcoholic or carbonated beverages, for an hour before the experiment. They were also told to avoid participating in strenuous exercise and to sleep on regular hours, one day before the experiment.

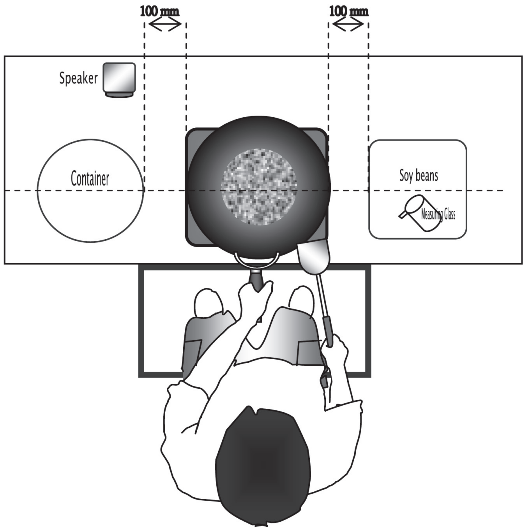
Experimental design

This experiment used a two factor randomized complete block design. The independent variables were the wok size (with three diameters of 36 cm, 39 cm and 42 cm) and the wok handle angle (with five angles of 25°, 10°, –5°, –20° and –35°; 10° is the original angle). The dependent variables were the maximum acceptable weight of wok flipping (MAWF), the subjective rating and the subjective ranking. Each subject performed only one combination per day, for a total of 15 combinations (3 wok sizes × 5 angles), in a random order. Once the subjects had completed all of the experimental combinations, the subjects assessed their subjective preference for each of the 15 woks that they used. To minimize the effect of weight, the sum of the weights of the wok and food it contained (soybeans in the woks) was used as the MAWF. In addition, to prevent the effect of other variables, the size of the cooking utensils was standardized, as follows: 25 cm, for the culinary spatula length, 25°, for the lifting angle, 9 cm, for the height of the gas stove, 24 × 12 cm for the container. The height of the working platform was adjusted to the subject's knuckle height. The lab temperature was maintained at between 22°C and 26°C. The relative humidity in the lab was maintained at between 55% and 75%.

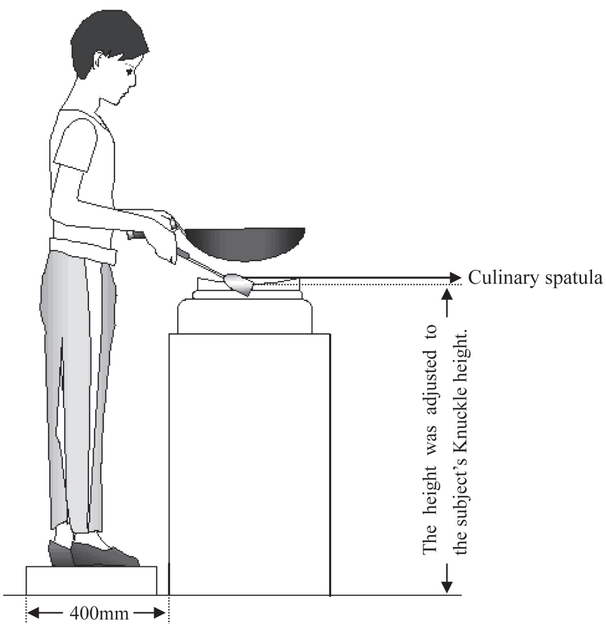
Apparatus

A workstation with an adjustable height was constructed, to allow simulation of the cooking task in a laboratory setting (Fig. 1). The equipment used in the experiment included a culinary spatula, a single-handle round bottom wok and a gas stove.

A total of 15 round bottom woks were used in this study. They were made by modifying the angle of the handle of commercially purchased woks. The three wok diameters (36 cm, 39 cm, and 42 cm) used in this experiment are shown in Fig. 2. The weights of the three woks were 1,094 g, 1,194 g and 1,387 g, for the 36 cm, 39 cm and 42 cm diameter woks, respectively. The handle angle of woks sold in Taiwan is approximately 10° above the horizontal. By testing and observing the changes in wrist joint angle, using biometrics, when a

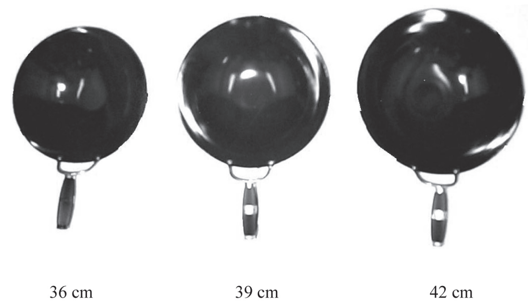


(a) Top view of the experimental layout

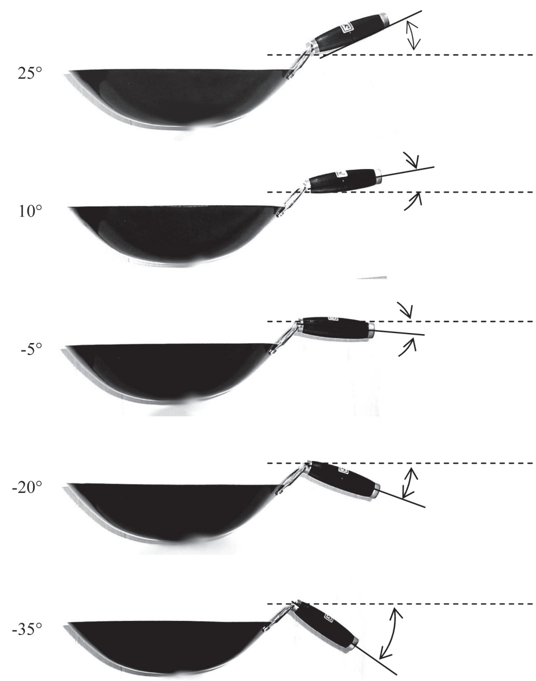


(b) Side view of the experimental layout

Fig. 1. Experimental layout.



(a) Three woks, of different diameters



(b) Bending angles of 5 wok handles

Fig. 2. Experimental woks.

subject held the wok handle, we found that when the wok handle angle was approximately –35°, the subject's wrist could remain neutral. As a result, the handle angles were set at 15° intervals, at 10°, –5°, –20°, and –35°. To determine the effect of the wok handle angle on the task of flipping the wok, a handle angle of 25° was further added, giving five different wok handle angles, i.e., 25°, 10°, –5°, –20°, and –35°, as shown in Fig. 2.

Subject training

Prior to data collection, four training sessions were conducted, to gradually condition the subjects to the different tasks, and to enable them to gain experience in adjusting the flipping weight and force. Each session lasted for half an hour. The training progressed as follows:

In the first training session, the subjects were asked to use three sizes of the standard wok (36 cm, 39 cm, 42 cm), with a handle angle of 10°, to practice their flipping. The purpose of this exercise was to familiarize then with the flipping task and with the muscle group used. Instructions were given through a loudspeaker. In the second, third and fourth training sessions, the subjects were asked to practice flipping 15 woks, in random order. They practiced flipping each wok for 2 min, including "adjusting the weight" and "flipping the wok, after determining the weight". They practiced adjusting the weight of the food in the wok, to determine the maximum acceptable weight.

Simulated wok flipping

When the subjects formally participated in the wok flipping experiment, they were required to read the experimental instructions, first, and then perform the warming-up exercise. The experimenter led the subjects in stretching/rotary exercises, for the shoulder, arm, wrist and palm, four times. The experiment then began.

The experimental stage was divided into three steps. Step 1 allowed the subjects to establish a base weight for the wok and its contents. Step 2 established the MAWF and Step 3 determined the level of fatigue and discomfort, associated with each wok design. Figure 3 shows the time line of the experimental task.

The first step involved "the subjects adjusting the starting weight, according to their preference", and lasted one minute. The subject held the wok handle with his nondominant hand. At this time, the upper arm of the nondominant hand was naturally down. Within one minute, he had to adjust the amount of soybeans in the wok, with his dominant hand holding the measuring glass, until the weight in the wok was acceptable, for the task of flipping.

The second step, "flipping the wok and adjusting the weight", lasted three minutes. The subject performed the flipping task and adjusted the weight, for 20 s, as one task cycle. At the beginning, the loudspeaker sounded, "Ready!" Immediately, the subject was required to get prepared. In two seconds the loudspeaker sounded, "Begin!" The subject was required to immediately lift the wok and flip it, three times, with his nondominant hand, and then put the wok down (Meanwhile, the loudspeaker made a "ka" sound, three times, to symbolize the frequency of the flipping task, that frequency being one sound per second.) so as to redistribute and evenly heat the soybeans in the wok. The subject was required to flip the wok, with the help of the culinary spatula, lest the soybeans drop out of the wok. If the subject thought the wok was too heavy, or too light, he could then adjust the amount of soybeans in the wok, with his dominant hand holding the measuring glass, until the weight represented the maximum they could flip without straining themselves or becoming unusually tired, weakened, overheated, or out of breath[28, 29]. When the subject had repeated the above task nine times, the loudspeaker instructed, 10 s from the end, "Adjust the weight, for the last time!" which reminded the subject to determine the weight, for the last time. In addition, after the ninth task cycle, the loudspeaker sounded, "Please hold the culinary spatula!"

When the subject held the culinary spatula with his dominant hand, the third step began. This was "flipping the wok after determining the weight", and lasted two minutes. Using the weight adjusted and determined in the second step, the subject performed the task, according to the instructions given by the loudspeaker. Each working cycle lasted 15 s. The loudspeaker firstly sounded, "Ready!" Two seconds later, the loudspeaker sounded, "Begin!" The subject was required to lift the wok and shake it, three times, with his nondominant hand, and then put it down. At this time, the subject was required to lift the culinary spatula with his dominant hand, to perform the simulated food stir-frying

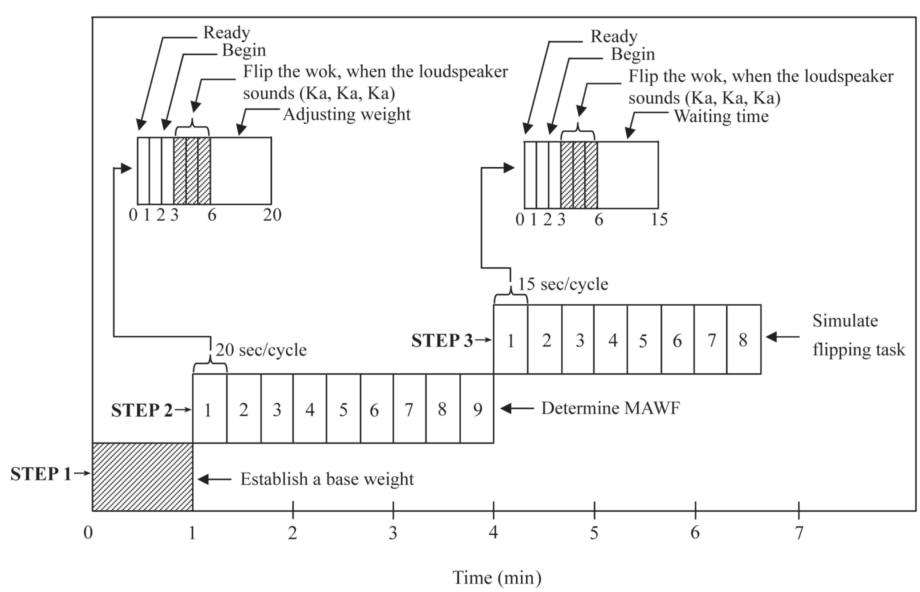


Fig. 3. The time line of the experimental simulated flipping task.

task, first from right to left and then from left to right and from front to back, three times in total. After evenly stirring the soybeans in the wok, he then stopped doing the task and waited for the next cycle. After the subject had performed the task eight times, the loudspeaker sounded, "Please empty the soybeans into the container on the left!" The subject then lifted the wok, with his nondominant hand, and emptied the soybeans into the container on the left. The subject then put the culinary spatula back into the center of the wok and the experimental task was finished.

At the end of the flipping task, the experimenter weighed the soybeans and wok, as the MAWF, and asked the subject to report on his level of fatigue and the feeling in various parts of his body, using the subjective rating scale. The subjective rating scale contained five adjective pairs: wrist aching - wrist not aching, arm aching - arm not aching, shoulder aching – shoulder not aching, gripping easily – gripping with difficulty and exerting easily – exerting with difficulty. Each pair had an unmarked scale, from one (aching or difficulty) to nine (not aching or easy)[24]. When the subject completed all of the experimental combinations, he was requested to rank his preference for the 15 woks, from 1 (favorable) to 15 (unfavorable).

Analysis

The experimental data were statistically analyzed, using the analysis of variance (ANOVA) method for two dependent variables: the maximum acceptable weight of wok flipping and the subjective rating. If a significant difference was noted, then Duncan multiple range tests were used for post hoc comparison. The subjects' subjective preferences for the 15 woks were analyzed using the Wilcoxon test.

Results

Maximum acceptable weight of wok flipping

The analysis of variance results show that the wok size and the angle of the wok handle have a significant effect on the MAWF ($p<0.05$). With regard to the wok size, the Duncan multiple range test in Table 1 shows that the weight for the wok with the 42 cm diameter (2,251 g) was greater than that for the woks of 36 cm (2,195 g) and the 39 cm diameter (2,174 g). There was no significant difference between the woks of 36 cm and 39 cm diameter. As shown in Table 1, the greatest handle angle was –35° (2,299 g), and the smallest handle angle was 25° (2,158 g). There was no distinct difference between the –20°, –5°, 10° and 25° handle angles. In addition, the ANOVA showed that the wok size and the wok handle angle did not interact with each other ($p>0.05$). Figure 4 shows the effect of the five different wok handle angles and the three different wok sizes on the MAWF. It is clear that the 42 cm diameter wok performed greatest, while the second greatest was the 36 cm wok and the 39 cm diameter wok performed smallest. In addition, the subject's MAWF increased, for different wok handle angles, except for the 10° wok handle on a 39 cm diameter wok.

Table 1. The Duncan Test of the MAWF, for the subjects

Variables	Levels	Average[a]	Grouping[b]
Diameter	42 cm	2,251.4	A
	36 cm	2,195.0	B
	39 cm	2,174.4	B
Angle	–35°	2,299.1	A
	–20°	2,208.2	B
	–5°	2,192.0	B
	10°	2,176.8	B
	25°	2,158.4	B

[a]Mean of the MAWF. Unit: g.
[b]A and B are two different Duncan groups; means with the same letter were not significantly different (α=0.05).

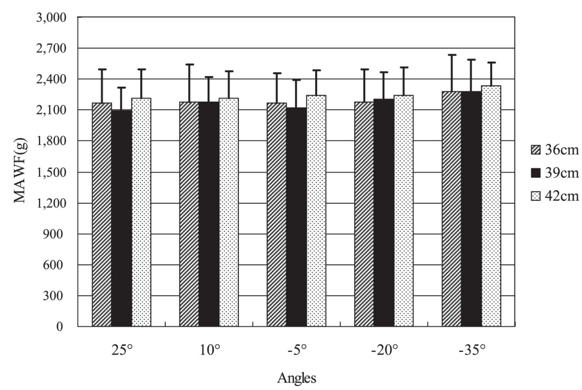


Fig. 4. The effect of handle angle and the diameter of the wok on the maximum acceptable weight, for flipping.

Subjective rating

The wrists, arms and shoulders

An analysis of variance showed that both the wok size and the wok handle angle had a significant effect on the subjective rating for the subject's wrists aching ($p<0.05$). The Duncan multiple range test (Table 2) shows that the rate of perceived exertion on the subject's wrist (4.3), for a 36 cm wok, was better than that for a 42 cm wok (3.5) and no significant difference was found from that for a 39 cm wok (4.0). The Duncan multiple range test shows that the wok handle with an angle of –20° (4.5) performed significantly better than those with angles of 10° (3.6) and 25° (3.1) and did not differ significantly from the performance of

Table 2. Summary of the Duncan Test, for the subjective rating

	Variables	Levels	Average[a]	Grouping[b]		
Wrists	Diameters	36 cm	4.3	A		
		39 cm	4.0	A	B	
		42 cm	3.5		B	
	Angles	–20°	4.5	A		
		–35°	4.3	A	B	
		–5°	4.1	A	B	
		10°	3.6		B	C
		25°	3.1			C
Arms	Diameters	36 cm	4.4	A		
		39 cm	4.3	A		
		42 cm	3.9	A		
	Angles	–20°	4.5	A		
		–35°	4.4	A		
		–5°	4.3	A		
		10°	4.1	A		
		25°	3.9	A		
Shoulders	Diameters	36 cm	6.0	A		
		39 cm	6.0	A		
		42 cm	5.7	A		
	Angles	–20°	5.9	A		
		–35°	5.9	A		
		–5°	5.9	A		
		10°	5.8	A		
		25°	5.8	A		
Grip	Diameters	36 cm	5.2	A		
		39 cm	4.2		B	
		42 cm	3.7			C
	Angles	–20°	5.3	A		
		–35°	4.8	A	B	
		–5°	4.2		B	
		10°	4.1		B	
		25°	3.3			C
Exertion	Diameters	36 cm	5.8	A		
		39 cm	5.0		B	
		42 cm	3.4			C
	Angles	–20°	5.5	A		
		–35°	5.3	A	B	
		–5°	4.6		B	
		10°	4.5		B	
		25°	3.7			C

[a]Mean of the subjective rating. Subjective rating scale from one to nine, the higher the better.
[b]A, B and C are three different Duncan groups; means with the same letter were not significantly different (α=0.05).

woks with handle angles of –35° (4.3) and –5° (4.1). The performance of the wok with a handle angle of 10° did not differ remarkably from that with an angle of 25°.

Both the wok size and the wok handle angle had no significant effect on the subjective rating for the subjects' arms aching and shoulders aching (p>0.05), as shown in Table 2.

Table 3. Summary of subjects' subjective ranking for the woks

Angle \ Diameter	36 cm	39 cm	42 cm	Average[a]
25°	8.9 (3.8)	10.5 (2.7)	12.9 (2.2)	10.7 (2.9)
10°	6.0 (6.1)	6.5 (3.8)	9.1 (3.6)	7.2 (3.5)
–5°	4.3 (4.3)	3.4 (2.4)	7.7 (3.4)	5.1 (2.8)
–20°	4.7 (4.8)	4.3 (3.0)	9.5 (3.6)	6.2 (3.0)
–35°	7.6 (7.7)	10.5 (3.9)	13.5 (2.8)	10.5 (3.6)
Average	6.3 (3.2)	7.0 (3.2)	10.5 (3.1)	

[a]Mean of subjective ranking.

Grip

Both the wok size and wok handle angle had a significant effect on the perceived grip rating (p<0.01). The Duncan multiple range test, in Table 2 shows that the wok with the 36 cm diameter performed significantly better than those with diameters of 39 cm and 42 cm. The Duncan multiple range test shows that the –20° angle was significantly better than angles of –5°, 10° and 25°, but did not differ significantly from that of –35°. Angles of –5° and 10° were significantly better than 25°, but not different from that of –35°.

Exertion

Both the wok size and handle angle had significant effects on the perceived exertion rating (p<0.01). As shown in Table 2, a wok with a diameter of 36 cm performed significantly better than those with diameters of 39 cm and 42 cm. The wok with a 39 cm diameter was significantly better than that with a 42 cm diameter. The Duncan multiple range test shows that an angle of –20° was clearly better than angles of 10° and 25°, but was not significantly different to angles of –35°. There was no significant difference between angles of –35°, –5°, and 10°, which were all significantly better than 25°.

Subjective ranking

In this research, the subjects' subjective preferences for the 15 experimental woks are shown in Table 3. The subjects graded the wok with a 36 cm diameter, best, and did not prefer the 42 cm diameter wok. The subjects graded the –5° wok handle angle, best. The –20° and –35° angles were second and third, while they did not prefer the 25° angle, at all. Further analysis of the Wilcoxon test of the subjects' subjective preferences shows that both the wok size and handle angle had a significant effect on the subjects' subjective preference (p<0.05). The woks were grouped into the Best,

Table 4. The Wilcoxon Test of subjective ranking for the 15 woks

Treatments	Average[a]	Significance[b]	Group[c]
39 cm × –5°	3.4	0.002	Best
39 cm × –20°	4.3	0.002	
36 cm × –5°	4.3	0.016	
36 cm × –20°	4.8	0.018	
36 cm × 10°	6.1	0.108	Middle
39 cm × 10°	6.5	0.557	
36 cm × –35°	7.7	0.394	
42 cm × –5°	7.8	0.284	
36 cm × 25°	8.9	0.587	
42 cm × 10°	9.2	0.422	
42 cm × –20°	9.6	0.099	
39 cm × 25°	10.5	0.040	Worst
39 cm × –35°	10.6	0.008	
42 cm × 25°	12.9	0.014	
42 cm × –35°	13.5	0.002	

[a]Mean of the subjective ranking,
[b]Wilcoxon test,
[c]Best, Middle and Worst are three different preference groups; means with the same group were not significantly different (α=0.05).

Middle and Worst, depending on whether their estimated median was significantly smaller than, not significantly different from, or significantly greater than 8.0, the expected median on a 1–15 ranking scale[24]. As shown in Table 4, the four woks that the subjects preferred best had 36 cm and 39 cm diameters with handle angles of –5° and –20°.

Discussion

Numerous factors influenced the comfort and performance of the cooks. This study focused attention on the effect of the wok size and handle angle on the MAWF, subjective rating and ranking. The results show that both the wok size and the handle angle significantly affect these criteria. The effect of interaction between all responses for the wok size and handle angle were not significant. Therefore, the ideal wok size and handle angle can be selected, independently from each other, without considering the combined effect of these two factors.

Effect of the wok size

As shown in Table 1, the MAWF of the 42 cm diameter was larger than that for the 36 cm and 39 cm diameter woks. Based upon biomechanical mechanisms, the center of gravity of a larger wok is relatively further from the exertion point of the wrist, which leads to a reduction in the maximum acceptable weight, for flipping. These conflicting results may be caused by the effect of the size-weight illusion[25]. In other words, the subjects perceive larger woks to be lighter than smaller woks of the same mass, so they lift greater masses. This phenomenon is very important, because any decrease in perceived heaviness of larger woks could cause the subjects to exceed the limits of safety. This finding was consistent with the previous study of Naylor and Amazeen[26].

As mentioned by Davis[27], when a hand-held object is lifted by wrist flexion, the lifting system composed of muscles, bones and the object lifted constitutes a third-class lever. Therefore, objects require greater lifting force, as they are supported further, distally. Similarly, a wok with a bigger diameter is usually quite heavy and its center of gravity is far from the hand. Therefore, if a subject flips a larger wok, he will be apt to feel fatigue in his wrists, arms and shoulders. It will also be difficult for him to hold and exert a force on the wok. Because of this difficulty in exerting a force on the wok, some uncoordinated postures and movements will occur, in his hands, causing low wok assessment scores. As shown in Table 2, the 36 cm wok was reported as the best, in the overall subjective rating, while the 42 cm wok was reported as the worst.

The results of the subjective ranking were also consistent with the subjective rating. Table 3 shows that subjects prefer a wok with a smaller diameter, because they feel that it is more comfortable and easier to lift and grip. As a result, in the subjective preference ranking, subjects preferred the 36 cm wok best and least preferred the 42 cm wok.

Figure 5 shows the comprehensive comparison of the three criteria related to the wok size. The criterion scales in Fig. 5 were converted into fairly arbitrary values. Only "desirable" and "undesirable" attributes are indicated[23, 24]. It can be seen that the 36 cm wok was the best, in the subjective rating and ranking. When considering the size-weight illusion effect, the 36 cm wok is, again, the preferred choice.

Effect of the angle of the wok handle

During flipping, the more the wok handle bends upward, the more serious is the deviation and flexion of the wrist. Under these circumstances, if a subject wants to flip the food in the wok, by exertion of his arms, his wrists bear too much burden. Table 1 shows that the –35° handle is best and the 25° handle is worst. The MAWF increases, from 25° to –35° because, when a wok handle with a downward angle is used, the user can keep his wrist neutral and avoid lifting his arm and shoulder. This improves the subject's MAWF. This finding was consistent with previous studies on other hand tools[19–22].

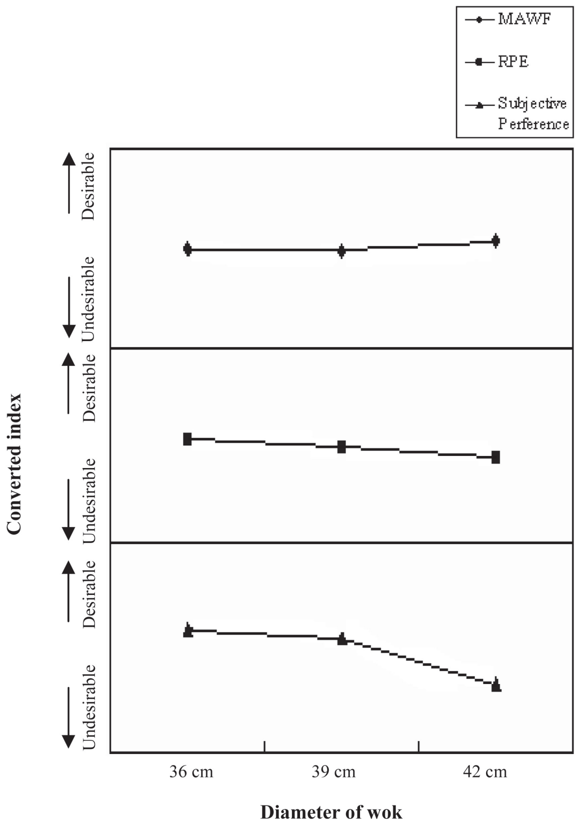


Fig. 5. Comprehensive effects, for different diameters of wok.

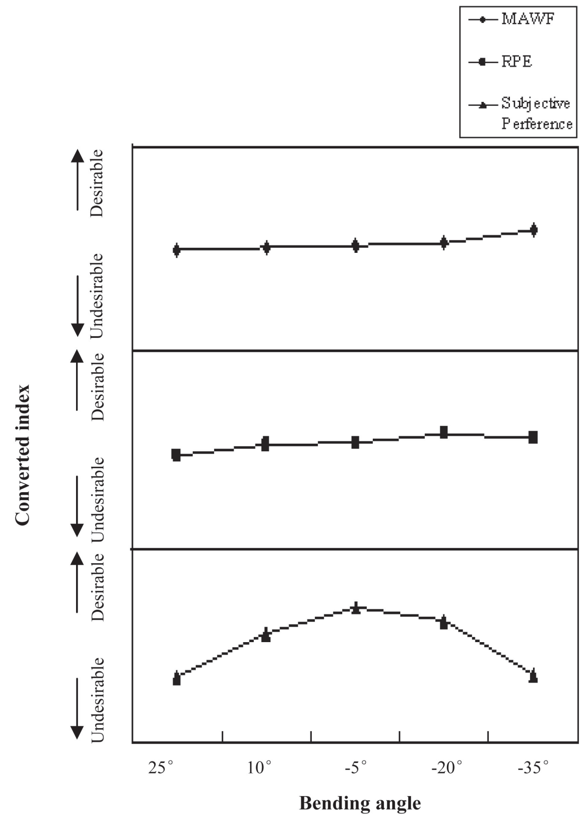


Fig. 6. Comprehensive effects, for woks with different handle angles.

The angle of the wok handle has a significant effect on the wrist, gripping and exertion, in the subjective rating. During flipping, the wok with a downward handle allows the user's wrists to assume a neutral posture, instead of a posture with ulnar deviation. As mentioned by Werner *et al.*[6], the angle of the wrist, during grip-type exertions, directly affects the amount of intra-wrist supporting forces acting normal to the direction of the tendons and their synovial joints. Because of this relationship, it is recommended that the wrist be kept relatively straight, during forceful gripping, to avoid large intra-wrist forces. Table 2 shows that the –20° handle was the best preferred, the –35° handle was the second best preferred, better than the 10° handle, while the 25° handle was the least preferred. In other words, the subjects rated the bent-handled woks better than conventional straight-handle woks.

Table 3 shows that the subjects preferred the –5° handle the most, the –20° handle second, the 10° handle third, the –35° handle fourth and the 25° handle the least. This is because when a user applies force to the wok with a downwardly angled handle, he can reduce the extent of the ulnar deviation in the wrist and effectively exert the force with his arm, so he is able to alleviate the discomfort in his wrist. However, when using the wok with the –35° handle, for flipping task, the fulcrum changes to the elbow and he must principally depend on the strength of his arm to control the wok. Although the arm has greater strength, it has less flexibility than the wrist. As a result, while flipping, the subject must accurately control the force exerted by his arm, lest the food drop out of the wok, while flipping. For this reason, subjects may prefer the wok handle with a smaller bent angle (–20°, –5° and 10°), which remains stable, when force is applied, and allows better control.

Figure 6 shows comprehensive comparison of the three criteria relating to the handle angle of a wok. Similarly to Fig. 5, the criterion scales in Fig. 6 are converted to "desirable" and "undesirable" attributes. As can be seen in Fig. 6, the –35° handle allowed the highest MAWF, the –20° handle scored best in the subjective rating and the –5° handle scored best in the subjective ranking. In general, the bent-handled woks were better than the straight-handled woks.

Conclusions

This study investigated the effect of wok size and handle angle on the maximum acceptable weight of the

Table 5. Summary of the optimal diameters and handle angles of a wok according to the 3 criteria

	MAWF	Subjective rating	Subjective ranking	Total (optimum)
Diameter	42 cm	36 cm	36 cm	36 cm
Bending angles	–35°	–20°	–5°	–5° ~ –35°

wok, for flipping, the subjective rating and subjective ranking.

Firstly, the results show that wok size significantly affects MAWF, subjective rating and subjective ranking. Considering the effect of the size-weight illusion on the MAWF, the 36 cm wok performed best.

Secondly, the results reveal that wok handle angle also significantly affects MAWF, subjective rating and subjective ranking. Overall, the ergonomically designed, bent-handled woks perform better than conventional, straight-handled woks.

Thirdly, this paper verifies that the effect of the size-weight illusion on MAWF is significant, in flipping tasks.

Finally, this study shows the 36 cm diameter wok with a –20° ± 15° bent-handle is ideal for cooks who prepare stir-fry dishes (Table 5).

However, since the simulated wok flipping task was performed in a laboratory and the subjects of this study were all young male cooks, it is not clear thief these results apply to females, or elderly cooks. Therefore, it is suggested that a field experiment, with a wider range of ages and variety of cooks should be conducted. In addition to psychophysical methods, biomechanical and physiological methods also should be used to determine the effect of the handle angle, for different wok sizes.

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References

1) Occupational Safety and Health Council (2000) Survey on occupational safety and health conditions of kitchen work in Chinese restaurants. Occupational Safety and Health Council, Hong Kong.
2) Gigstad J (2002) Ergonomic analysis of production cooks at XYZ high school, The Graduate School University of Wisconsin-Stout Menomonie, Wisconsin.
3) Chyuan JY, Du CL, Yeh EY, Li CY (2004) Musculoskeletal disorders in hotel restaurant workers. Occup Med **54**, 55–7.
4) Chyuan JY (2007) Ergonomic assessment of musculoskeletal discomfort among commissary foodservice workers in Taiwan. Journal of Foodservice Business Research **10**, 73–86.
5) Leamon TB, Dempsey PG (1995) The unusual congruence between subjective evaluations and losses associated with inadequate hand tool design. Int J Ind Ergons **16**, 23–8.
6) NIOSH (1997) Musculoskeletal disorders and workplace factors: a critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity and lower back. NIOSH Publication NO.97-141, DHHS, Cincinnati.
7) Okunribido OO, Haslegrave CM (1999) Effect of handle design for cylinder trolleys. Appl Ergon **30**, 407–19.
8) Li KW (2002) Ergonomic design and evaluation of wire-tying hand tools. Int J Ind Ergon **30**, 149–61.
9) Buckle PW, Devereux JJ (2002) The nature of work-related neck and upper limb musculoskeletal disorders. Appl Ergon **33**, 207–17.
10) Werner R, Armstrong TJ, Bir C, Aylard MK (1997) Intracarpal canal pressures: the role of finger, hand, wrist and forearm position. Clin Biomech **12**, 44–51.
11) Armstrong TJ, Chaffin DB (1979) Carpal tunnel syndrome and selected personal attributes. J Occup Med **21**, 481–6.
12) Tanaka S, Wild DK, Seligman PJ, Halperin WE, Behrens VJ, Putz-Anderson V (1995) Prevalence and work-relatedness of self-reported carpal tunnel syndrome among US workers: analysis of the occupational health supplement data of 1988: National Health Interview Survey. Am J Ind Med **27**, 451–70.
13) Tichauer ER, Gage H (1977) Ergonomics principles basis to hand tool design. Am Ind Hyg Ass J **38**, 103–16.
14) Emanuel J, Mills S, Bennett J (1980) In search of a better handle. *In*: Proceedings of the symposium: human factors and industrial design in consumer products, Medford. Tufts University, Medford.
15) Tichauer ER (1966) Some aspects of stress on the forearm and hand, in industry. J Occup Med **8**, 63–71.
16) Armstrong TJ, Foulke JA, Joseph BS, Goldstein SA (1982) Investigation of cumulative trauma disorders in a poultry processing plant. Am Ind Hyg Ass J **43**, 103–16.
17) Cochran DJ, Riley MW (1986) The effects of handle shape and size on exerted force. Hum Factors **28**, 253–65.
18) Bobjer O (1989) Ergonomic knives. *In*: Advances in Industrial Ergonomics and Safety I, Mital A (Ed.), 291–98, Taylor & Francis, London.
19) Schoenmarlin RW, Marras WS (1989) Effects of the handle angle and work orientation on hammering; I: wrist motion and hammering performance. Hum Factors **31**, 397–11.
20) Schoenmarlin RW, Marras WS (1989) Effects of the handle angle and work orientation on hammering; II:

Muscle fatigue and subjective ratings of body discomfort. Hum Factors **31**, 413–20.
21) Lewis WG, Narayan CV (1993) Design and sizing of ergonomic handles for hand tools. Appl Ergon **24**, 351–6.
22) Hsu SH, Chen YH (1999) Evaluation of bent-handled files. Int J Ind Ergon **25**, 1–10.
23) Hsu SH, Wu SP (1991) An investigation for determining the optimum length of the chopsticks. Appl Ergon **22**, 395–40.
24) Wu SP, Hsieh CS (2002) Ergonomics study on the handle length and lift angle for the culinary spatula. Appl Ergon **33**, 493–501.
25) Luczak H, Ge S (1989) Fuzzy modeling of relations between physical weight and perceived heaviness: the effect of size-weight illusion in industrial lifting tasks. Ergonomics **32**, 823–37.
26) Naylor YK, Amazeen EL (2004) The Size-Weight Illusion in Team Lifting. Hum Factors **46**, 349–56.
27) Davis CM (1973) Mechanical advantage in the size-weight illusion. Percept Psychophys **13**, 238–40.
28) Ciriello VM, Snook SR (1983) A study of size, distance, height, and frequency effects on manual handling tasks. Hum Factors **25**, 473–83.
29) Wu SP, Chen JP (2003) Effect of the adjustment period on psychophysically determined maximum acceptable weight of lift and physiological cost. Int J Ind Ergon **31**, 287–94.