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DESIGN, CONSTRUCTION AND TESTING OF A PORTABLE HAIR TWISTING DEVICE

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ABSTRACT
The research work presents the design/concept, construction and testing of a rechargeable hair twisting device. The twisting device was designed and constructed scrap components obtained from existing devices such as rechargeable torch light, video tape re-winder. The constructed hair twisting device is portable and has features that enable it to twist up to four strands of hair at a time. It weighs 234.3 g which means it is portable and light and will not be stressful to the end user when used for prolong operation. It is relatively faster (53.58 – 57.97% times) than manually plaited hair, but organoleptic assessment indicates that it is not as appealing compared to manually plaited hair. However, there is still room for improvement in the area of look and feel (beauty) which is the main reason why women takes time out to plait.
***Keywords**: Braiding, Hair, Hairstyles, Plaiting, Twisting.*

INTRODUCTION

The appearance and aesthetics of the hair are a frequent concern of women around the world (Franbourg *et al*., 2003). Whether as a fashion statement or an indicator of social status, braided hairstyles for both men and women have remained prevalent in many cultures for centuries (Choe and Ko 2005; Yuksel *et al*., 2009).

A hairstyle refers to the styling of hair, usually on the human scalp. The style of the hair arises from humans' natural need for beauty and the knowledge that the thickness and colour of the splendour of the hair helps to determine the impression which we make on the world around us. But hairstyles make us not only beautiful and attractive; they also inform us about the customs and characteristics of an age or about the social standing and profession of a person (Sherrow, 2001).

The basic techniques used in hair styling include (i) Braiding (ii) Twisting and (iii) Threading. A braid also referred to as a plait (Plate 1 A) is a complex structure or pattern formed by interlacing one or more strands of flexible material such as textile fibres, wire, or hair. Braids have been made for thousands of years according to Peter (1992). Different types of braid hairstyles exists such as; (a) English Braid, (b) French Braid, (c) Dutch Braid, (d) Swiss Braid, (e) Rope Braid and (f) Multi-Strand Braid according to Smith (2014). Braids have been discovered at Peruvian burial sites dating as far back as 8600 – 5780BC in the form of ropes, looped bags, and twined fabrics (Owen, 2004); these braids are likely to have been created far before their woven counterparts due to their simple formation and highly functional value.

The invention of the braiding machine is primarily attributed to Thomas Walford for his 1748 patent which described a machine or engine for " the laying or intermixing of threads, cords, or thongs of different kinds, commonly called plaiting" (Ko *et al.*, 1989). Hair twists (Plate 1 B) are a hairstyle popular with Afro-textured hair in the United States, and sometimes with other hair textures. The style is achieved by dividing the hairs into several sections, twisting strands of hair, then twisting two twisted strands around one another (Johnson, 2008). Threading simply refers to as hair knotting with thread, usually black in color (Plate 1 C). There are about 53 patents (worldwide) on different design of equipments related to hair braiding – meant to address the complications encountered in the process of hair plaiting (braiding). Earliest ones are by William (1913), Julius (1923), Hidesuke (1931), Payson (1961), Wool (1969), Eronini and Abia (1977), Jurgis (1983) etc. Iheanyichukwu E. Eronini and Abia Sunday Abia (Eronini and Abia, 1977) filed the earliest patent (US4038996) from Nigeria on December 3, 1975 and the latest from Nigeria is by Olayinka Ogunro (Ogunro, 2000) - filed on Sep 29, 1999 with patent number US6164289. However, the most current patent (worldwide) is patent number WO2014028761A1, by Giving (2014).

A B C

Plate 1: Hair styles - (A) Dutch braiding (Luxyhair, 2019), (B) Twisted hair (Del. 2017), (C) Threading (Femi, 2018)

However, in spite of the significance of hair plaiting (hairstyling) in complementing beauty as an indicator of social status, as a characteristic of an age and as an informant about the custom of a person, the availability of competent hair stylist in our community is an issue of great concern. Another problem at hand is that in locations where competent hair stylists are available, the time of completion and the ratio of stylist to customers are discouraging factors that lure away lovers of hair styling. Also, there had been few researches on hair plaiting/twisting device particularly in Nigeria. A problem that needs attention is the skin disorder acquired at a stylist saloon (Archibong *et al.*, 2018) or some due to the hair style itself (Fox *et al.*, 2007), a personally owned dressing equipment can eliminate or reduce this as it is done with hair clippers.

Building an hair styling device is justified for the following reasons; scalp skin health disorder can be eliminated, it will save time (for other useful things of life), dexterity of hair styling will no longer be the commercial hair stylist affairs, and the economy will be contributed to positively.

It is the goal of this research to design, fabricate and test a hair twisting machine. We also want to implement a portable device that is light weight. Furthermore, we intend to evaluate it with a real subject.

MATERIALS AND METHODOLOGY

Description of the hair twisting device

The hair plaiting device (shown in Figure 1) consists of two main parts:

The static part (Figure 2)
The rotating head (Figure 3)

The static part includes the charging port, the rechargeable battery, the switch, the motor. The rechargeable battery is charged via the charging port. The switch powers the motor on when it is in the ON position. The electric motor transmits rotational motion to the compound gear train consisting of four (4) sets of satellite gears via the shaft.

The rotating head consists of two rotating components; the compound gear casing and the twirling pins. The rotation of these components is controlled by the four simple gear trains of the compound gears arranged as shown in the exploded view of the rotating head assembly of Figure 4 and the phantom view of Figure 5. The clasping pins are spring loaded such that the hair strand is held firmly by the twirling pins while still allowing it to slip by as the twisting operation progresses.

Operation of the hair twisting device

Strands of hair are first combed straight and placed in the hair clasps at the end of each twirling pin. To open the hair clasp, the clasp is pushed upwards. The end of the hair strands are then clasped in the clasp. The process is repeated for all the twirling pins. The device is then switched on while the unit is held away from the subject head with a bit of tension to make a perfect, tight twirl all the way to the root. Thereafter, the device is switched off. The newly twisted hair is then carefully released by pushing the clasps upwards.

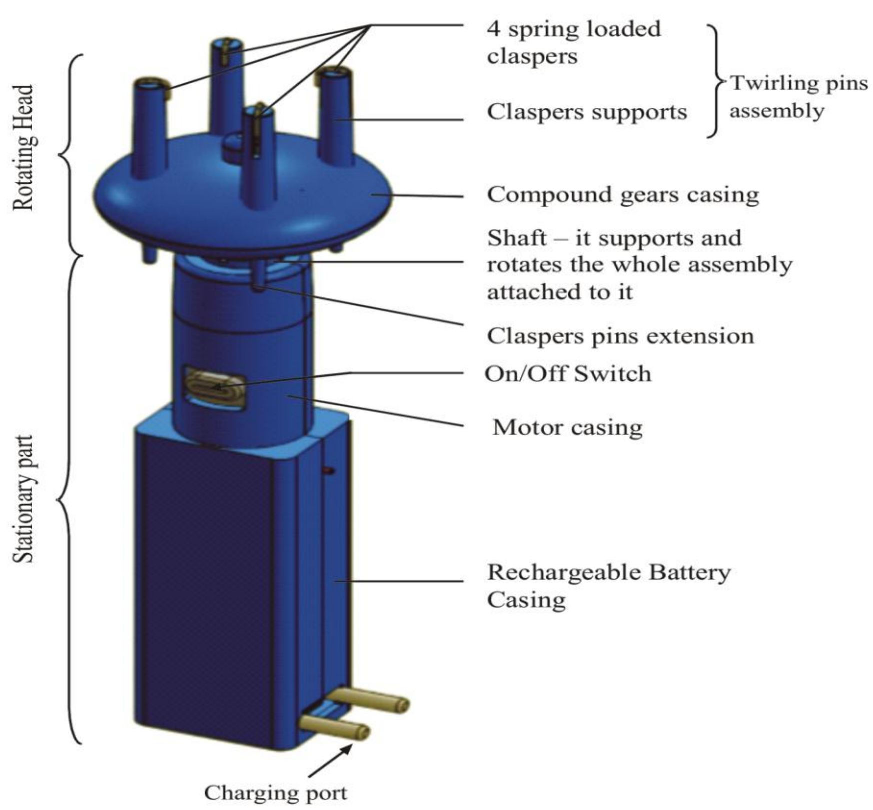


Figure 1: The hair twisting device

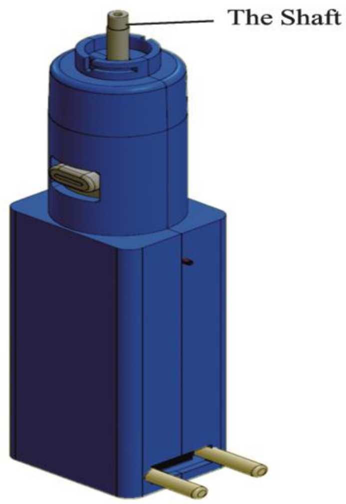


Figure 2: The stationary part

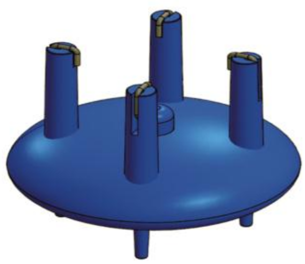
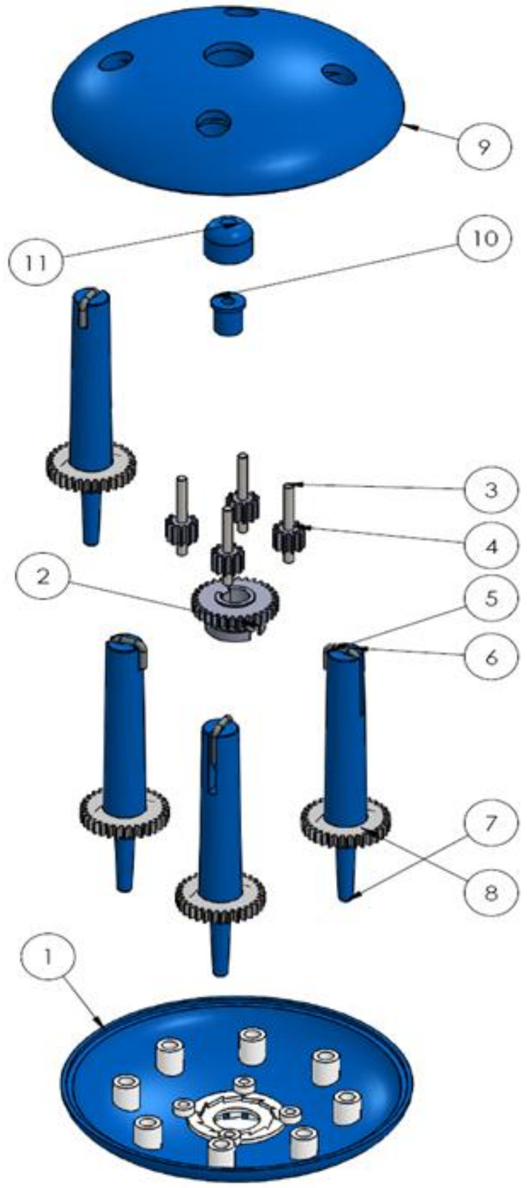


Figure 3: The rotating head



Item	Part Number	Qty
1	Twisting Head bottom	1
2	Sun Gear	1
3	Connecting pin	4
4	Planet Pinion	4
5	Twirling Pin	4
6	Hair Clasp	4
7	Clasp Push	4
8	Simple Gear Disc	4
9	Twirling Head Top cover	1
10	Main bushing	1
11	Head Cap	1

Figure 4: Exploded view of the head

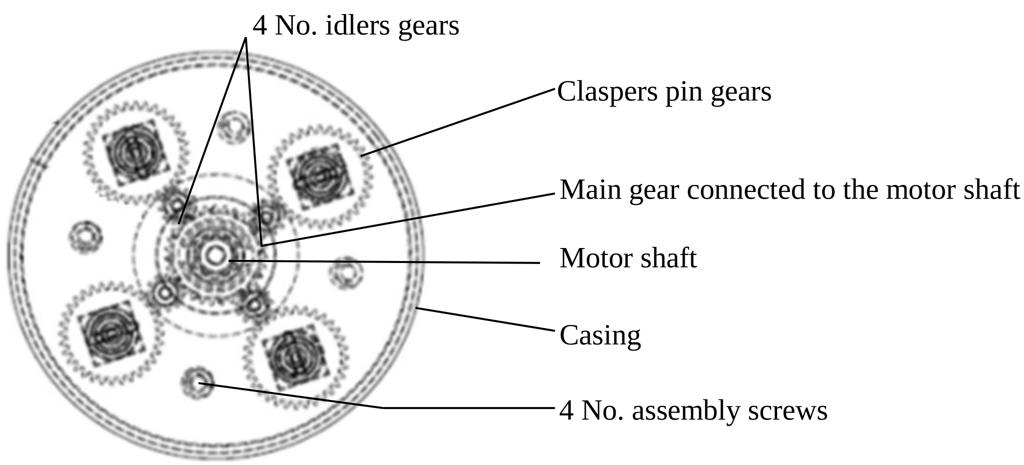


Figure 5: The compound gears of the rotating head - plan view of the phantom view

Design Consideration

The limiting factor in the implementation of the design presented in this work is portability and the torque required to twist the hair strands held in its claspers. This means that all the components must be light weight. The battery must be light weight while still having enough power density to run the device without the need to replace it or recharge it. The motor needs to be light weight also while delivering the torque needed to power the rotating head and the gear mechanism. A lithium ion battery was selected for the rechargeable battery since its lightweight and has high power density and is commonly available for use in many portable devices including mobile phones. A Teflon gear was preferred for the gears since it has very low wear, low maintenance, low coefficient of friction ranging from 0.05 to 0.20 and are also lightweight being a plastic.

Components Design and Specification

The really critical components used in developing this device are the planetary gear, the electric motor and the rechargeable battery and the shaft connecting the motor to the gear;

Power requirements of an electric motor

A D.C motor is used for driving the sets of gears in this project. The power supply required to drive the D.C motor is obtained from a battery. The power requirements, motor speed and weight are the determining factors in selecting a suitable motor for this device.

(i) The power to drive an ordinary permanent magnet motor is given as:

$$w = V*I*\eta \quad (1)$$

where, V = applied voltage

I = current flowing = $I_{running} + I_{idle}$

$I_{running}$ = current consumed while running

I_{idle} = current consumed while idle

η = efficiency of the motor

Also, $\mathbf{W} = 2\pi*N*T$ (2)

where, N = circular speed (rev /s)

T = Torque (Nm)

(ii) The desired rotating speed – This is fixed at 3000 rpm to be stepped down to 10 rpm using gear trains

(iii) The weight of motor – A light weight motor that meets the above two criteria is preferred.

The Rechargeable Battery

The limiting factor in battery selection is the current it's able to supply when in use. The minimum time of use (that is, the time it takes to finish one set of hair cluster to be twisted) is assumed to not exceed 1minute. The current demand is thus given as follows (a rearrangement of Equation 1).

$$I = w / V*\eta \quad (3)$$

where;

w will be the maximum power the motor will require

V = applied voltage = 4.8v for this project

η = is the efficiency of the motor

The Gear Set

The following are the factors considered in gear design implemented in this work; Tangential tooth load, Static tooth load, Dynamic load and Wear tooth load.

(i) Determination of the tangential tooth load - The design tangential tooth load is obtained from the power transmitted and the pitch line velocity using the following relation;

$$W_T = \frac{P}{V} \times C_S \quad (4)$$

where, W_T = Permissible tangential tooth load in Newton.

p= Power transmitted in watts and

$v = \frac{\pi DN}{60}$ =Pitch line velocity in m/s (5)

D= Pitch circle diameter in meters

N= Speed in r.p.m *and*

C_S = Service factor

The values of service factor for different types of loads (Steady load, Light shock, Medium shock and heavy shock) can be found in Khurmi and Gupta (2008).

Circular pitch, P_C is given as;

$$P_C = \frac{\pi D}{T} = \pi m \quad (6)$$

Thus the pitch line velocity may also be obtained by using the following relation, i.e

$$V = \frac{\pi DN}{60} = \frac{\pi m.T.N}{60} = \frac{P_C.T.N}{60} \quad (7)$$

where,

m=Modules in metres and

T= Number of teeth

(ii) Determination of the static tooth load (W_S) - The static tooth load (also called beam strength or endurance strength of the tooth) is obtained by Lewis formula by substituting elastic limit stress or flexural endurance limit (σ_e) in place of permissible working stress (σ_w). (Khurmi and Gupta, 2008)

That is;

$$W_s = \sigma_e.b.p_c y = \sigma_e.b.\pi.m.y \quad (8)$$

(iii) Determination of the dynamic load (W_D)

The design dynamic load (W_D) on the tooth is obtained by using Buckingham equation. That is;

$$W_D = W_T + W_I \quad (9)$$

For pulsating loads,

$$W_s \geq 1.35 W_D \quad (10)$$

where, W_I =Incremental load due to dynamic action.

$$W_I = \frac{21v(b.c+W_T)}{21v+\sqrt{b.c+W_T}} \quad (11)$$

(iv) Determination of the wear tooth load (W_w) - The design wear tooth load is gotten by;

$$W_w = D_P.b.Q.K \quad (12)$$

where, Q= $Ratio\ factor$

K= $load\ stress\ factor$

(v) The Gear ratio - The motor speed of 3000 rpm is reduced to 187.25 rpm using the gear ratio determined as follows; speed of the motor gear, N_1=3000 rpm.

$$T_2 = T_4 = T_6 = T_8 = 18 \quad (13)$$

$$T_1 = T_3 = T_5 = T_7 = 9 \quad (14)$$

where, $T_1, T_2 \ldots are\ no.of teeth\ of gear$ 1,2,..8

speed of rotation of gear 8 (the last gear in the series);

$$\frac{N_1}{N_8} = \frac{T_2 \times T_4 \times T_6 \times T_8}{T_1 \times T_3 \times T_5 \times T_7} = \frac{3000}{N_8} = \frac{18^4}{9^4} \therefore N_8 = 187.25rpm$$

Shaft Design
The limiting factors in the shaft selection for this work are the power transmitted, axial load on it, the diameter of the shaft, bending and torsional stress.

(i) Power transmitted to the shaft - the power transmitted by shaft (in watts) is related to the torque by;

$$p = \frac{2\pi NT}{60} \quad (15)$$

(ii) Axial force acting on the shaft – this is given as:

$$T_A = F \times r_A \quad (16)$$
$$T_A = T_B \times \frac{r_A}{r_B} \quad (17)$$

(iii) Determination of the shaft diameter - this was determined using this relationship.

$$d = \sqrt[3]{\frac{16T}{\pi \times \tau}} \quad (18)$$

τ =Permissible torsional shear stress
d = Diameter of shaft

(iv) The bending moment acting on shaft- the bending moment on a shaft is given by;

$$M = \frac{\pi}{32} \times \sigma_b \times d^3 \quad (19)$$

where, σ_b is the bending stress

(v) The combined bending and twisting moment acting on shaft

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{M^2 + T_t^2} \quad (20)$$

Design of the claspers spring
The claspers spring are simple helical coils to be used actively in compression mode.

(i) The spring constant (K) and spring index
The spring constant of a helical compression spring is defined as the load required per unit deflection of the spring and is given by Budynams and Nisbett (2013) as;

$$k = \frac{W}{\delta} \quad (21)$$

The spring index is also given as;

$$C = \frac{D}{d} \quad (22)$$

where, δ= static deflection of the spring (in mm) and
W = the spring static load (in Newton)

(ii) Determination of the solid length and free length of the spring
The solid length of the spring is the length of the spring when the coils come in contact with each other. It is also given as;

$$L_s = n'd \quad (23)$$

The free length of the spring is the length of the spring in the free or unloaded condition. It is given as;

$$L_f = n'd + (n' - 1) \quad (24)$$

where;
n' = Total number of coil

(iii) The permissible shear stress and the number of active turns
The permissible shear stress in the spring is given by;

$$\tau = K_S \frac{8WD}{\pi d^3} \quad (25)$$

where, K_S = Shear stress factor and is given;

$$K_S = 1 + \frac{1}{2C} \quad (26)$$

The number of active turn is given by;

$$n' = \frac{Gd}{8C^3k} \quad (22)$$

where, k =Wahl's stress factor and is given by;

$$k = \frac{4C-1}{4C-4} + \frac{0.615}{C} \quad (27)$$

Using the following input data,
1. Permissible torsional shear stress of Teflon $(\tau) = 1.5 \times 10^6$ N/m^2
2. Bending stress $(\sigma_b) = 18$ N/mm^2
3. Free length of the spring $(L_f) = 7$ mm
4. Total number of coil $(n') = 6$
5. Permissible shear stress $(\tau) = 651$ Mpa

The followings specifications (Table 1) were arrived at for the device.

Table 1: Summary of the design calculation

Part	Result
No. of teeth of the motor gear	9
Face width of the motor gear	5 mm
Gear tooth load (W)	1.02 N
Gear static load	0.11 N
Dynamic load	W≤ 0.08 N
Speed of the driven gear	N=187.25,ω=19.64rad/s
Power transmitted to the driven gear	P=0.0025 w
Diameter of the shaft attached to the gear	d= 4.2 mm
Bending and twisting moment acting on the shaft	σ=8.94N mm
Rotational speed of the shaft	N=47.7rad/s and ω=5 rad/s
Electric motor torque	$(T_{1t}) = 0.002$ Nm
Motor output power	0.6 watt
Desired motor speed (N) =	3000 rpm

Mabuchi FA-130RA or FA-130SA DC motor (Plate 2) are both adequate enough to power the twisting head, they both weigh 17 g. However, Mabuchi FA-130SA is preferred because it has a slightly higher power rating of 0.2-9.0W. Other parameters are, Nominal Voltage - 3V, at maximum efficiency the RPM - 10740, Current - 1.05A, Torque - 1.37 mN.m, Power rating - 1.54 W and uses carbon brush.

Plate 2: The D.C motor used - Mabuchi FC-130RA/SA

Two lithium ion battery (Plate 3) in parallel has the low weight criteria and has a running voltage of 4.8v (which is higher than that required to drive the motor). The BLC Lithium ion battery (by Sony Ericsson) can supply more than 1.7A (2 X 850 mA each) which is more than adequate to drive the motor at its peak efficiency.

Plate 3: Lithium ion battery

Labour and Overhead

The cost of materials, fabrication, assembling and estimated labour cost is presented in Table 2. It all amount to N10,900:00 only.

Table 2: Labour cost estimates

S/No.	Items	Amount (N)
1	Materials	4,400
2	Fabrication and assembly	3,500
3	Labour	1,000
4	Transportation	2,000
Total		10,900

TESTING OF THE HAIR PLAITING (TWISTING) DEVICE

Portability test

A digital weighing scale was used for measuring the assembled device so as to find out how heavy it was.

Twisting time

A stop watch was used in determining the time required to complete a twist of a four set of strand of hair by the device and three set of strand of hair by hand.

Twisting test procedure

The testing of the hair twisting device followed these steps (see Plates 4 a- 4c);

i. A minimum of two strands and a maximum of four strands of hair were selected.

ii. Each strand was combed straight and placed at the hair clasps at the end of each twirling pin. To open the hair clasp, the clasp was pushed upwards. The end of at least 12.7 mm (1/2 inch) of hair was clasped in the hair clasp.

iii. The process was repeated for other strand, with one strand per twirling pin.

iv. The on-off switch was pushed upwards (i.e. on), the twirling pins rotate making the individual strand of hair twirl separately.

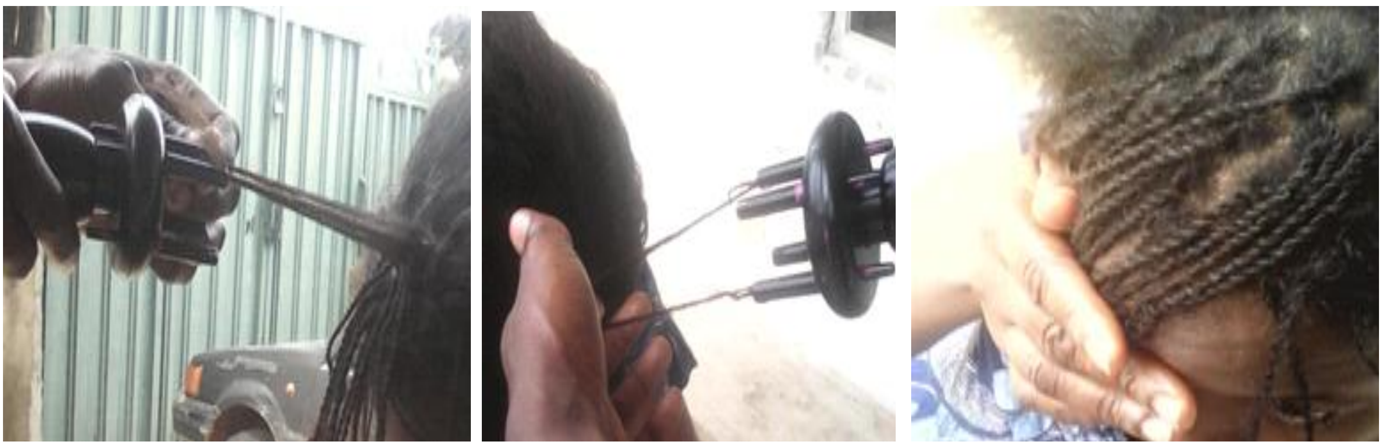
v. The unit was held away from the head with a bit of tension to make a perfect, tight twirl all the way to the root.

vi. The on-off switch was pushed downwards (i.e. off), the twisting head rotates allowing the strands of twirled hair to twist together forming a perfect and uniform twist.

vii. The strand was carefully released by pushing the clasp push upwards and the end of the twist was firmly held.

viii. The end of the twist was then secured with a rubber band or a bead clips.

ix. The manual test was done by an experiences stylist.



A B C

Plate 4 (A): Fixing the hair strands into the clasps. Plate 4 (B): The twisting process in operation. Plate 4: (C) The finished hair.

RESULTS AND DISCUSSION

Portability Test

The plaiting device weighs 234.3 g (Plate 5), thus it is a really portable device. For comparison purpose, a can of Multina (Malt) Drink weighs 353.24 g.

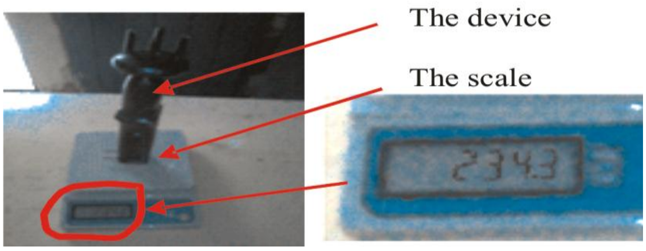


Plate 5: The Device on the weighing scale

Twisting time

The constructed hair twisting/plaiting device was tested and compared with the manual twisting/plaiting approach and the result is indicated in Table 3. Two range of hair lengths were used; L1=130 mm-170 mm and L2=171 mm-210 mm.

The average time in seconds for plaiting two, three and four strands of hair lengths L1 and L2 using the device and manual approach were recorded as shown in the Table 3.

Table 3: The average time for manual and device plaiting

	Manual plaiting		Device plaiting	
Test	L_1	L_2	L_1	L_2
1	47.7	53.2	20.2	22
2	59.2	64.2	25	29.8
3	-	-	32	34.4

Percentage Time Saved

The percentage time saved in plaiting using the constructed device and the manual approach for plaiting both two and three strands of hair of lengths L1 and L2 are showed in the Table 4.

Table 4: The time saving compared to manual process

Strands	L1	L2
1	57.65%	58.6%
2	57.97%	53.58%

Finished Twisted/Plaited Hair Assessment

The finished hair was compared with that manually plaited/twisted hair and the followings were observed:
The firmness of the manually plaited/twisted hair is superior to that done with the machine.
The end of the plaited/twisted hair is loose compared to that with the manually plaited/twisted hair.
Discomfort was much with the plaited/twisted hair done manually.

RECOMMENDATIONS

The followings are recommended for further research:
The design of hair twisting device should be for both hair braiding and threading as this device can only carry out hair twisting.

The hair clasp of the constructed device should be redesign to be more rigid with a rough clasping surface to ensure a more firmly grip, as we constantly experience slippage. This slippage is responsible for the poor finishing of the hair.

CONCLUSIONS

The design and construction of the rechargeable hair twisting device was successfully carried out. The constructed hair twisting device can effectively twist up to four strands of hair at a time, it eliminates the complete dependent on electric power supply in its operation, it is handy and does not involve any complicated technicality to operate it. The performance results show that the hair twisting device reduced the time required to complete a twist by more than 50% of the time required to carry out the twisting manually.

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