الطباعة ثلاثية الأبعاد للأطراف الصنعية العلوية بين الطموح والواقع

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الملخص

الخلفية: تهدف هذه الدراسة إلى تحري رضا المستخدمين السوريين للأطراف الصنعية العلوية المطبوعة بالطباعة ثلاثية الأبعاد خلال الاستخدام اليومي في المنزل، وتأثير نماذج الأطراف المطبوعة على رضا المستخدمين، ومعدلات التخلي عن استخدام الأطراف الصناعية العلوية المطبوعة بتقنية الطباعة ثلاثية الأبعاد بين المستخدمين.

الطرائق والمواد المستخدمة: طُبعت ثلاثة نماذج مفتوحة المصدر للأطراف الصنعية بالطباعة ثلاثية الأبعاد (gripper thumb, Unlimbited arm, and Kwawu arm) وذلك بعد المسح الرقمي ثلاثي الأبعاد للجزء المتبقي من البتر وتقييس النموذج ليلائم المستخدم، حيث زود 16 مشارك لديه بتر طرف علوي أحادي الجانب بأحد النماذج المطبوعة. قيمت النسخة العربية من تقييم كيبيك لرضا المستخدم عن تكنولوجيا وسائل المساعدة بعد ثلاثة أشهر من تلقي المشاركين لأطرافهم المطبوعة للاستخدام المنزلي.

النتائج: الرضا منخفض 2.75 بين مستخدمي الأطراف الصنعية المطبوعة، والمستخدمون غير راضين عن المظهر والأبعاد والراحة. ويؤثر مظهر النموذج للطرف المطبوع على رضا المستخدمين، وكان معدل التخلي عن الأطراف المصنعة 56.25%

الخلاصة: توجه نتائج البحث التطوير المستقبلي للأطراف العلوية المصنعة بتقنية الطباعة ثلاثية الأبعاد لتلبية احتياجات المستخدمين وتخفيف التخلي المستقبلي عن الأطراف الصناعية العلوية

كلمات مفتاحية: الطباعة ثلاثية الأبعاد للأطراف الصناعية- QUEST 2.0 – مبتور الأطراف الصنعية العلوية- الرضا

1 مخبر الطباعة ثلاثية الأبعاد 3DMED في كلية الهندسة الميكانيكية والكهربائية- جامعة دمشق

2 كلية الهندسة الطبية – جامعة الأندلس الخاصة للعلوم الطبية

3 كلية هندسة المعلومات والاتصالات – الجامعة العربية الدولية

3D Printed Upper Limb Prosthetics: Ambition & Reality

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Background: This study investigates Syrian users' satisfaction with 3d printed upper-limb prostheses for home use, the effects of 3d printed prosthetic models on users' satisfaction, and the abandonment rate of 3d printed upper-limb prostheses between them.

Materials and methods: Three open-source prosthetic hand models (gripper thumb, Unlimbited arm, and Kwawu arm) were printed after 3D scanning and scaling the model to fit the user. Sixteen participants with unilateral upper-limb loss were fitted with one of these prostheses. The Quebec User Evaluation of Satisfaction with Assistive Technology (Arabic version) was evaluated after three months from receiving the prostheses for home use.

Results: Satisfaction is low (2.75) among 3D printed prosthetic users. Users are not satisfied with appearance, dimension, and comfort. The appearance of 3D printed prosthetic models affect satisfaction and abandonment rate (56.25%)

Conclusions: Research findings can guide future 3d printed prosthetic device development to satisfy user needs and mitigate future upper-limb prosthetic device abandonment.

Keywords: 3d printed prosthesis; QUEST 2.0; upper-limb amputee, satisfaction.

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Introduction:

In Syria, suitable upper-limb prostheses are critical because upper-limb prosthetic technology is either not accessible, not meeting user needs, or both [1]. Additive manufacturing is an innovative technology utilized in creating prostheses for people with upper-limb loss in low-income countries because of lightweight, low cost, straightforward to use, and open-source design available for printing on consumer printers[2]. However, satisfaction rises as an issue for home or long-term use because if the user is not satisfied with the prosthesis, he will abandon it. Besides, satisfaction interfaces with prosthetic design characteristics like functionality, durability, weight, shape, and effectiveness [3–6].

The benefits of 3D printed prostheses are media-hyped. The users expect more satisfaction and functionality than reality [7, 8]. Satisfaction with 3D-printed prostheses was just measured to validate their design once users receive them or after a short period of use[9–11]. For instance, Zuniga found that six users were satisfied with the 3D printed prostheses[10]. The limitations of these studies include: small sample of participants ranging from a single subject to six for a short period [9–11].

Improvement of current 3D printed prostheses based on the demands of prostheses users requires evaluating users' satisfaction for home use to identify the benefits and drawbacks. However, none of the researchers measure the effects of different 3D printed prosthesis models on satisfaction. They concern about durability and functionality [7, 11, 12] while ignoring the importance of satisfaction to mitigate upper-limb prosthetic device abandonment since the abandonment rate is high between upper-limb prostheses users ranging from 6% to 100% for passive prostheses, 80% to 87% for body-powered prostheses and up to 75% for myoelectric prostheses[13].

This study investigates Syrian users' satisfaction with 3d printed upper-limb prostheses for home use, the effects of 3d printed prosthetic models on users' satisfaction, and the abandonment rate of 3d printed upper-limb prostheses between them.

Methods and materials:

Subjects:

Sixteen subjects (11 males and 5female) participate during this study (table (1)). All of them have unilateral trans-radial amputation except S1 who was born with a partial hand deformity. Their age 23.44±17.89 years with 8.87±7.5 years since amputation. They were amputated because of congenital deformities (8 participants) or trauma (5 war-injured, 2 work injured, and one car accident). Eight of them haven't received any prosthesis before while the others are using cosmetic prostheses without any movements.

Table 1: Participants' general characteristics.

Id	Gender	Age	Years Since limb loss	Amputation Cause	Limb loss Side	Used Prosthesis Before	Printed Model
S1	Male	12	12	Congenital Deformity	Right	No	Unlimbited
S2	Male	7	7	Congenital Deformity	Right	Yes	Gripper Thumb
S3	Male	47	7	War-injury	Right	Yes	Kwawu_Arm
S4	Male	4	4	Congenital Deformity	Left	No	Gripper Thumb
S5	Female	11	1	Car Accident	Right	Yes	Unlimbited
S6	Male	58	2	Work Injury	Right	No	Kwawu_Arm
S7	Female	12	12	Congenital Deformity	Left	Yes	Kwawu_Arm
S8	Female	27	27	Congenital Deformity	Right	Yes	Kwawu_Arm
S9	Male	8	8	Congenital Deformity	Right	No	Unlimbited
S10	Female	3	3	Congenital Deformity	Left	No	Gripper Thumb
S11	Male	44	26	Work Injury	Right	Yes	Unlimbited
S12	Male	35	7	War-injury	Right	No	Unlimbited
S13	Male	35	7	War-injury	Right	No	Kwawu_Arm
S14	Female	8	8	Congenital Deformity	Right	No	Unlimbited
S15	Male	21	4	War-injury	Left	Yes	Kwawu_Arm
S16	Male	43	7	War-injury	Right	Yes	Kwawu_Arm

3D printed open-source hand models:

Figure (1) demonstrates three open-source designs of 3D printed prosthetic hands that were printed. The first model was the gripper thumb developed by Skip Meetze and modified by the Grit3d team (the model files are available in [14]). It is a passive prosthesis that is suitable for children. It consists of a moving thumb and hand. The thumb moves by torsion spring.

The second model was the Unlimbited arm which is a body power prosthesis developed by Steve Davies with Drew Murray, and available for partial hand and trans-radial amputations, so it could be a wrist or elbow driven device [15].

The third model was the Kwawu arm was design by Jacquin Buchanan as a body power prosthesis driven by elbow motion with mechanical wrist joint and more cosmetic shape [16].

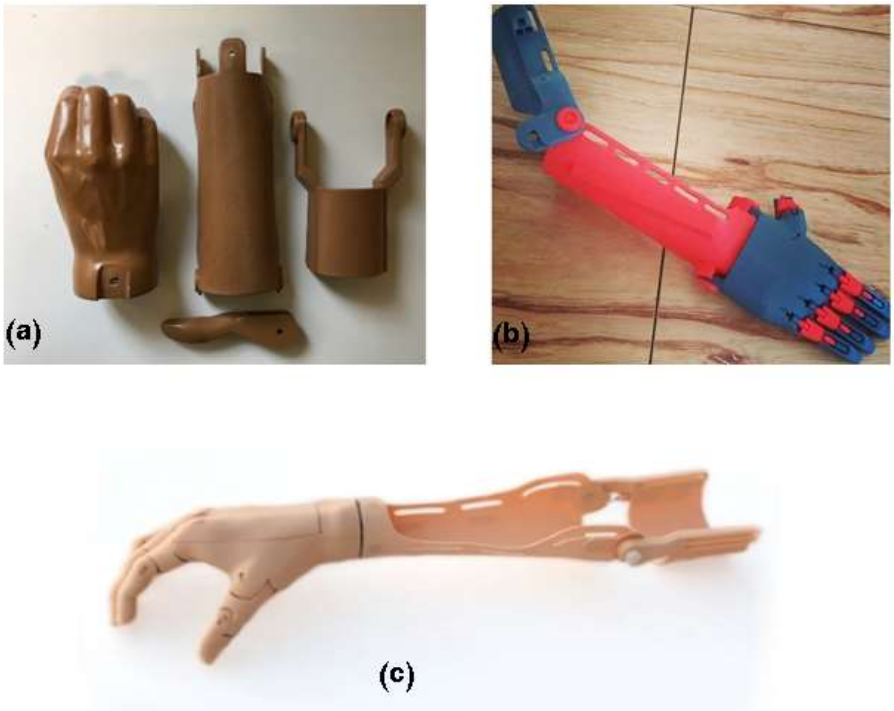

Figure 1: Three open-source prosthetic models: (a) Gripper thumb. (b) Unlimbited arm. (c) Kwawu arm [14–16].

Manufacturing process:

The manufacturing process follows the steps illustrated in figure (2). First, participant basic information was taken (age, amputation cause, using prosthetic hand before, years since amputation). Then, tape measuring and photos were taken for both hands. These measures include hand length, forearm length, biceps circumference, and arm circumference. After that, scans were taken for both upper-limbs using the STO1 scanner (Structure sensor from occipital, USA). The scaling process was performed using the OpenScad file provided with the model, which exports STL files designed based on the measurements and ready for printing after verifying the dimensions of the part by comparing them to the scanned limbs on Autodesk MeshMixer software. Two 3D Fused Decomposition Modelling printers were used to print the prostheses (Delta WASP 20x40, Delta WASP 40x70, WASP, Italy). All prosthetic hand models' components were printed in ECOGENIOUS PLA (from Treed, Italy) except flexible parts were printed in ULTRAFLEX XX (from Treed, Italy). The setting of printing follows prosthetic designers' recommendations. During prosthesis fitting, all patients required simple adjustments to their prosthesis like changing string tension to improve grasping, changing velcro straps and foam attachment place, and some thermoforming.

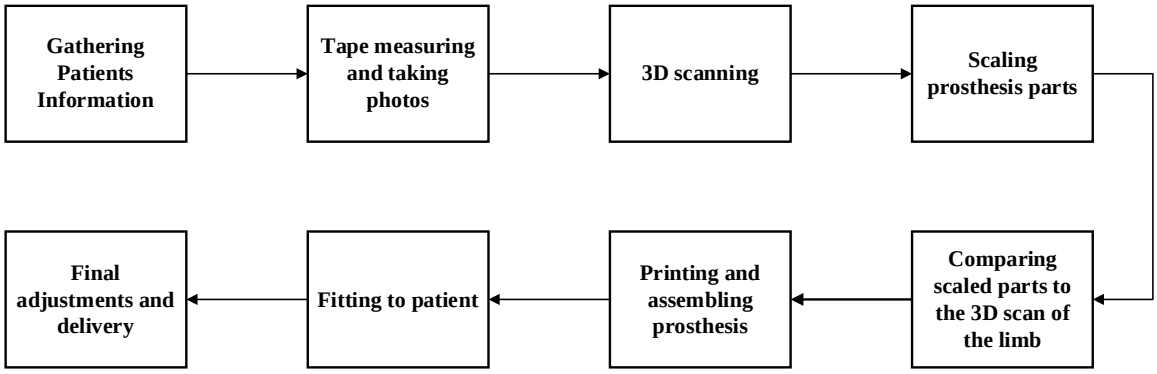

Figure 2: manufacturing steps for 3D printed prosthetic arm.

Satisfaction interviews:

After at least three months from using the 3d printed prosthetic hand, interviewers used a cell phone for asking Quebec User Evaluation of Satisfaction with assistive Technology questionnaire QUEST 2.0. This questionnaire developed by Demers [17] and validated in Arabic version QUEST-AR 2.0 by Bakhash [18, 19]. The QUEST-AR 2.0 consists of an 8-item device domain and a 4-item service domain. Each item is rated on a four-point ordinal scale graded from 1 (not satisfied at all) to 4 (very satisfied). The QUEST-AR 2.0 yields three scores: device, services, and total QUEST 2.0, which are calculated by averaging the valid responses to assigned items. To identify the sources of user satisfaction or dissatisfaction, a space for comments. Interviewers concentrate on device items in QUEST, in addition to asking the participants about the usage and what were the main problems they faced during the usage and if they have any suggestions to improve this prosthesis to be more satisfied.

Statistical analysis:

Data were analysed using SPSS 25.0 statistical software. Chi-squared analysis was applied to comparisons of categorical groups of QUEST-AR 2.0 that are 4 Likert scale items while differences between model's users were evaluated using the Kruskal-Wallis test.

Results:

Sixteen Syrian with upper-limb loss fitted with 3D printed prosthesis hand for at least three months. Three kids were fitted with the passive prosthesis model (gripper thumb) while the reminder fitted with the body power prostheses (7 Kwawu arms and 6 Unlimbited arms) as shown in figure (3). The results are divided into three paragraphs: users' satisfaction with 3D printed devices, Models effect on users' satisfaction, and usage rates.

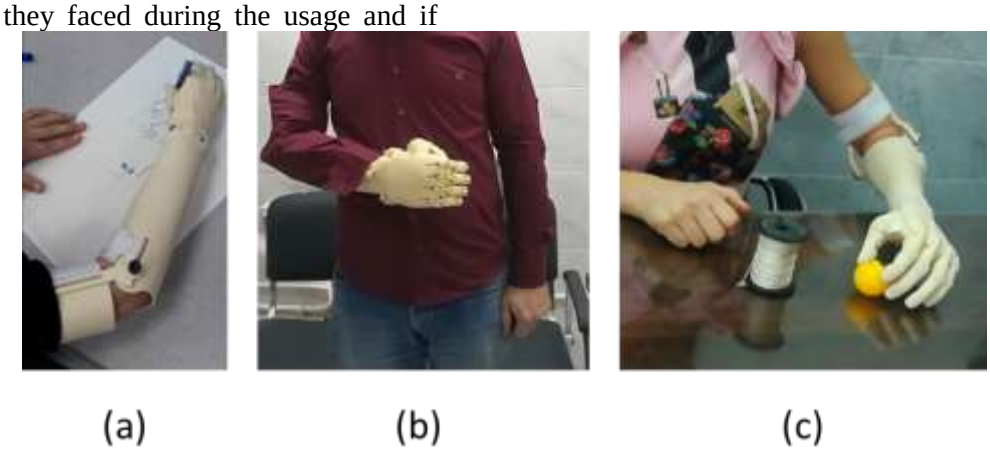

Figure 3: Participants training to use the 3D printed prostheses: (a) Gripper thumb. (b) Unlimbited arm. (c) Kwawu arm.

Users satisfaction with 3d printed devices:

Table 2 shows that 3D printed prosthetic hand's users are satisfied (2.75) with their devices. They are very satisfied (81%) with weight, durability, and free of pain while they are not satisfied with dimensions (52%), comfortable (56%), and appearance (50%).

Table 2: QUEST-AR 2.0 with 4 Likert scale items, means, standard deviations, and percentage of satisfaction for 16 participants.

ID	Item	strongly agree	agree	disagree	strongly disagreed	mean	SD	%	Satisfaction
Q1	My device fits well	1	5	4	6	2.06	0.97	52	disagree
Q2	The weight of my device is manageable	8	6	0	2	3.25	0.97	81	strongly agree
Q3	My device is comfortable throughout the day	1	6	5	4	2.25	0.9	56	disagree
Q4	It is easy to put on my device	6	5	2	1	2.88	0.91	79	agree
Q5	My device looks good	0	5	6	5	2	0.79	50	disagree
Q6	My device is durable	10	2	2	2	3.25	1.09	81	strongly agree
Q7	My device is pain-free to wear	10	3	0	3	3.25	1.15	81	strongly agree
Q8	My skin is free of abrasion and irritation	9	3	1	3	3.13	1.17	78	agree
	Total					2.7578	0.55	68.9	

Model Designs' effects Satisfaction:

The users of the Unlimbited model are not satisfied with their devices (2.38) while the others are satisfied (gripper thumb users 2.54, Kuwau arm users 3.05). They strongly disagree with dimensions and appearance while they disagree with durability and comfort.

Only appearance (Q5 My device looks good) shows statistical significance (p=0.02) between model user groups because there are significant differences (p=0.01) in satisfaction between Kuwau model users and Unlimbited model users who are not satisfied with the appearance as shown in table (3).

Table 3: QUEST-AR 2.0 with 4 Likert scale items, means of satisfaction with 3D printed prostheses models (gripper thumb, Kuwau arm, Unlimbited arm).

ID	Item	Gripper Thumb	Kwawu arm	unlimbeted arm
Q1	My device fits well	2.33	2.29	1.67
Q2	The weight of my device is manageable	3.67	3.57	2.67
Q3	My device is comfortable throughout the day	2.33	2.57	1.83
Q4	It is easy to put on my device	2.00	3.00	3.17
Q5	My device looks good	2.00	2.57*	*1.33
Q6	My device is durable	4.00	3.00	2.00
Q7	My device is pain-free to wear	2.00	3.86	3.17
Q8	My skin is free of abrasion and irritation	2.00	3.57	3.17
	Total	2.54	3.05	2.38

Figure 4 shows that users are satisfied with weight (Q2) but not satisfied with dimensions (Q1) despite the model of 3D printed prostheses. Additionally, to weight, Kuwau arm model users are satisfied with comfort and appearance, while gripper thumb model users are only satisfied with durability.

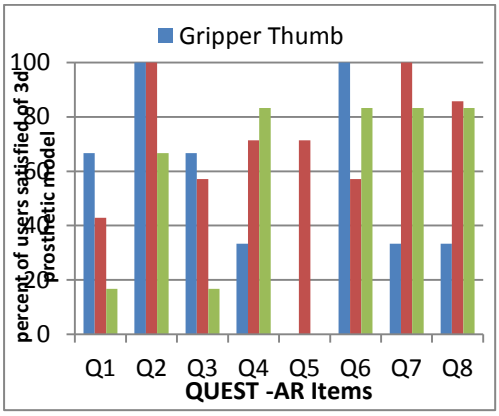

Figure 4: Percent of users' satisfaction with 3D printed prostheses models using QUEST –AR items that are the sum of agree and strongly agree items.

Abandonment rate of 3d printed upper-limb prostheses:

The percent of participants who abandon the 3D printed prostheses was 56.25%. The abandon percentage for each model was 33.3%, 57.14%, and 66.6% for gripper thumb, Kwawu arm, and Unlimbited arm respectively (figure). The appearance and dimensions were the key factors to abandon the 3D printed prosthetic models. Users of Kwawu arm and gripper thumb who abandon their prostheses said that their family and partners affect their decisions to abandon the prosthesis even the advantage of lightweight which is not available in other types of prostheses, for instance, mothers of S4, S8, and wife of S11 forbade S4, S8, S11 from wearing the prosthesis just after two days of use.

The participants pointed out increasing stigmatization due to the unacceptable appearance and dimensions of the prostheses. They felt obliged to stop wearing their prostheses in social situations, they said words like " It's embarrassing to go outside with this prosthesis, could you add a cosmetic glove for it" (all of them). " wear gloves to hide it" (S13, mother of S7 and S10). " wear it at home only, other people will laugh if you show it up" (mothers of all participants under 18). Only Unlimbited arm model users faced functionality problems like: threads were cut out, elastic bands that return fingers backs wear out quickly, parts near the joints between cuff and forearm or palm were broken, and thumb position made wearing clothes harder.

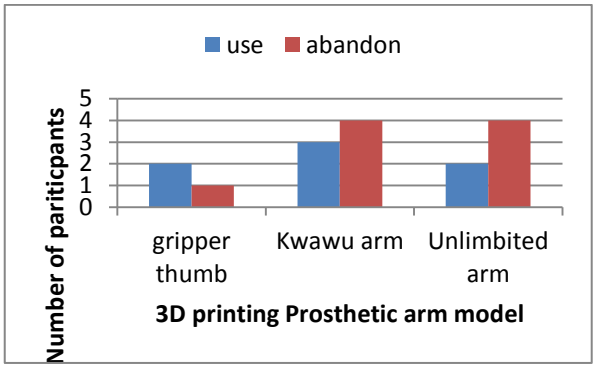

figure 5: Number of participants who use or abandon the 3D printed prostheses.

Discussion:

3D printing has opened many opportunities for prosthetic hands for assistive purposes. This paper endeavoured to answer whether the openly accessible designs of 3D printed prosthetic hands are satisfactory for Syrian users or not. QUEST-Ar 2.0 provides a qualitative description of the subject's feelings toward specific aspects of the prosthesis. The results from QUEST-Ar 2.0 showed that satisfaction was low with 3D printed devices which is opposite to Zuniga's finding. This difference can be related to culture since Arabic culture doesn't accept people with disabilities easily [20]. Syrian community could be described as a collectivistic society, where 3D printed prostheses could increase users' stigmatization. Vlachaki demonstrates that prosthetic limbs with unattractive appearance negatively affected participants' wellbeing [21]. Because of the differences in appearance between the 3D printed prostheses, there was a difference in satisfaction between users. Kwawu arm users were more satisfied than others that since the Kwawu arm model has a wrist, a good appearance, and more functionality compared with other models.

The rate of abandoned 3D printed prostheses is 56.25% that is lower than other body-powered prostheses 80% to 87% [13]. It is because of users' stigmatization by people close to users such as their family members. when a person is born with or develops a disability there is less expectation that he or she will assume or resume social roles and activities in a collectivistic society like Syria. This means that despite lightweight satisfaction with 3D printed prostheses, the advancements of 3D printed upper-limb

prosthetics have not yet achieved a significant change in prosthetic abandonment rates compared with other prosthetic types [3, 22].

Conclusion:

QUEST-AR 2.0 measures Syrian participants' satisfaction after home use of 3D printed prostheses. Their satisfaction is low. Improvements in current open-source 3D printed prostheses are needed especially appearance, durability, and dimensions to be more satisfying. Syrians upper-limb amputees and their families need more social and psycho support services to cope with their disability besides community awareness programs to remove the stigma from prostheses' users and accept them in society with their differences.

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- Each participant was provided with information about the study and provide verbal consent. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.
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Disclosure statement:

The authors report no conflicts of interest.

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