NATIONAL ENGITECH DIGEST

VOL. 3 ISSUE 1

e-ISSN: 3030-5969

Development and User-Centred Evaluation of a 3D-Printed Assistive Tool for Vehicle Fuel Cap Opening

Nur Raihana Sukri[1*], Nur Adriana Iman Mohd Harman[2], Chanjey Rajapandian[3]

[123] Department of Mechanical Engineering, Politeknik Ungku Omar, Perak, Malaysia

nur_raihana@puo.edu.my, adrianaahrmn@gmail.com, chanjeyr@gmail.com

Abstract

Opening a vehicle fuel cap can be difficult for people with reduced hand strength or upper-limb functional limitations. This preliminary study developed assistive-tool concepts and collected feedback at Hospital Taiping. Four concepts were developed, and two PLA prototypes were evaluated using five-point Likert questionnaires. The dataset contained 11 end-user evaluations (Design 1: n = 6; Design 2: n = 5) and four evaluations by occupational therapists from the Rehabilitation Department, Hospital Taiping (n = 2 per design). Overall item-based means ± sample standard deviations were 3.93 ± 0.63 and 4.04 ± 0.46 for end-user evaluations, and 5.00 ± 0.00 and 3.63 ± 0.52 for occupational therapist evaluations of Designs 1 and 2, respectively. Exploratory internal-consistency estimates for the 14-item user questionnaire were α = 0.922 and 0.943, although the small samples preclude firm psychometric conclusions. Feedback prioritised hand support, grip security, handle configuration and cap engagement. Design 1 was selected for further development based on occupational therapist judgement; the final product was printed in ABS. The contribution is a set of stakeholder-informed requirements for a task-specific fuel-cap opening tool. The results describe preliminary perceptions, rather than clinical effectiveness or verified mechanical benefit.

Keywords: Assistive technology; rehabilitation; user-centred design; hand function; additive manufacturing

Introduction

Hand function is important for performing everyday activities independently. Tasks involving grasping, twisting, pulling, and manipulating objects may become difficult for individuals experiencing reduced grip strength, impaired motor control, joint limitations, or other upper-limb functional restrictions. Such limitations may affect both activities of daily living and instrumental activities required for independent participation in the community.

Vehicle operation provides an example of an everyday activity that requires adequate upper-limb function. Opening a vehicle fuel cap generally requires the user to establish a secure grip and generate sufficient rotational force to overcome the resistance of the cap. Although mechanically simple, the relatively small gripping surface and rotational nature of the task may present difficulties for individuals with reduced hand strength or impaired upper-limb function. An assistive tool that increases the effective gripping area and improves force transmission may potentially reduce the physical demand associated with the task.

Assistive technology provides an important approach for compensating for functional limitations and supporting independence (Bulut, 2026; Atigossou et al., 2025). Recent developments in additive manufacturing have expanded opportunities for producing low-cost and customisable assistive devices (Silva et al., 2025). Three-dimensional (3D) printing enables relatively rapid fabrication of complex geometries and facilitates iterative modification according to user requirements. These characteristics are particularly relevant to rehabilitation applications, where assistive devices may need to accommodate differences in hand dimensions, strength, range of motion, and functional capability.

However, successful assistive-device development requires consideration beyond mechanical functionality. An assistive device should also be comfortable, safe, intuitive, ergonomically appropriate, and acceptable to its intended users (Rasmussen et al., 2026). In rehabilitation-oriented applications, professional input is also important because occupational therapists can provide insight into functional performance, user limitations, safety, and practical application within daily activities (Fundarò et al., 2026). Therefore, incorporating both professional and end-user perspectives can provide complementary information during early-stage assistive-technology development.

A further challenge is that assistive technologies are frequently designed around broad categories of activities, whereas highly task-specific mechanical difficulties may receive less attention (Lingampally et al., 2024). Vehicle fuel-cap manipulation represents one such task. A relatively simple tool designed specifically to improve grip and

rotational force transmission may potentially assist individuals who experience difficulty performing the task independently.

Accordingly, this study aimed to develop and conduct a preliminary user-centred evaluation of 3D-printed assistive-tool designs for vehicle fuel-cap opening. The specific objectives were to: (i) develop functional assistive-tool concepts based on the requirements of the fuel-cap opening task; (ii) evaluate the developed prototypes from end-user perspectives in terms of ease of use, ergonomics, effectiveness, safety, and satisfaction; and (iii) obtain preliminary occupational therapy feedback regarding clinical suitability, ergonomics, safety, functional benefit, and potential practical application. The study was designed as an early-stage prototype evaluation rather than a clinical effectiveness trial.

Methodology

a. User-Centred Design Approach

A user-centred product development approach was adopted to incorporate functional requirements and stakeholder feedback during the early development of the assistive tool. The development process began by identifying the principal requirements associated with vehicle fuel-cap manipulation. These included secure engagement with the fuel cap, adequate hand support, improved force transmission, ease of operation, and safe interaction between the device and the user's hand.

Multiple design concepts were subsequently developed using computer-aided design (CAD). The concepts explored different handle geometries and gripping configurations intended to increase the effective gripping area and facilitate rotational manipulation of the fuel cap. Four preliminary design concepts were considered during the development stage. Following preliminary design consideration, two prototypes were selected for demonstration and user evaluation. The prototypes were fabricated using fused deposition modelling (FDM) 3D printing with polylactic acid (PLA) filament. PLA was selected because of its accessibility, ease of printing, dimensional stability, and suitability for rapid prototyping during the iterative design process. The use of FDM enabled rapid fabrication and modification of the prototypes based on feedback obtained during the development and evaluation stages.

b. Prototype Evaluation

The two selected prototypes, shown in Figure 1, were demonstrated and evaluated with permission from the Director of Hospital Taiping. The tool and operating procedure were presented to occupational therapists from the Rehabilitation Department, Hospital Taiping; a QR-linked questionnaire was supplied for electronic feedback. The evaluation involved two stakeholder groups: end users and occupational therapy professionals. Four occupational therapy professionals participated in the professional evaluation and provided a clinical and functional perspective on the prototypes.

The end-user group consisted of 11 respondents, including individuals with reported functional limitations and individuals associated with patients. The reported functional limitations included reduced hand strength, stroke-related impairment, frozen shoulder, and age-related functional weakness. Because the participant group included both patients and family members, the group is referred to as end-user respondents in this study rather than exclusively as patients.



Figure 1. Two prototypes were demonstrated.

c. Evaluation Instrument

A structured five-point Likert-scale questionnaire was used for the evaluation. The response scale ranged from 1 (Strongly Disagree) to 5 (Strongly Agree), with higher scores representing more favourable evaluations. End users evaluated the prototypes using 14 items distributed across five domains: ease of use; ergonomics; effectiveness; safety; and user satisfaction. OT professionals evaluated the prototypes using 15 items covering: clinical suitability; ergonomics; safety; functional benefit; and potential for practical application. OT professionals were additionally invited to provide their clinical experience and qualitative recommendations regarding potential improvements to the designs.

d. Data Analysis

Responses were converted to numerical scores ranging from 1 to 5. Descriptive statistics were used to calculate the mean score for each evaluation domain and overall design score for each respondent group. Because of the small exploratory sample, the analysis focused on descriptive patterns rather than inferential statistical testing. Differences between Design 1 and Design 2 were therefore interpreted as indicative of response patterns rather than statistically established differences. Qualitative comments from end users and OT professionals were reviewed to identify recurring design requirements and potential improvements. These comments were used to inform interpretation of the quantitative findings and recommendations for subsequent prototype development.

Results and Discussion

a. End User Evaluation

Exploratory overall Cronbach's alpha was 0.922 for user Design 1 (n = 6) and 0.943 for Design 2 (n = 5). However, Design 1 domain estimates were lower for ease of use (0.397) and ergonomics (0.063). High overall alpha therefore does not validate all subscales or establish construct validity.

The end-user evaluation demonstrated generally favourable perceptions of both assistive-tool designs (Table 1). User evaluations were broadly favourable, with overall means of 3.93 for Design 1 and 4.04 for Design 2. The difference of 0.11 is descriptive and does not establish superiority. Design 2 received higher means for ease of use, ergonomics, perceived safety and satisfaction; Design 1 scored higher for perceived effectiveness.

Table 1. End user evaluation of the two assistive-tool designs.

Evaluation Domain	Design 1 mean ± SD	Design 2 mean ± SD
Ease of Use	4.22 ± 0.50	4.33 ± 0.47
Ergonomics	4.00 ± 0.42	4.27 ± 0.43
Effectiveness	3.75 ± 0.76	3.30 ± 0.45
Safety	3.67 ± 0.92	4.07 ± 0.72
User Satisfaction	3.94 ± 0.93	4.00 ± 0.71
Overall Mean	3.93 ± 0.63	4.04 ± 0.46

These findings suggest that the principal development challenge may extend beyond basic handling and include the interaction between the user's hand, the assistive tool, and the fuel cap. Importantly, the current study did not directly measure torque, grip force, or mechanical efficiency. Therefore, the lower effectiveness ratings should be interpreted as perceived effectiveness rather than evidence of objectively inadequate force transmission.

b. Occupational Therapy Professional Evaluation

Occupational therapist Design 1 Cronbach's alpha was undefined because all scores were identical; no occupational therapist reliability conclusion was drawn from only two records per design. Formal content and construct validity were not established by this reanalysis; occupational therapist product evaluation is not equivalent to expert validation of questionnaire items.

Occupational therapist records as shown in Table 2 gave Design 1 the maximum score on every item (5.00 ± 0.00). Design 2 had an overall score of 3.63 ± 0.52. Design 1 was selected for further development based on occupational therapist feedback and judgement, rather than a statistically demonstrated optimum. With two occupational therapist records per design, maximum ratings do not establish clinical suitability or safety. The questionnaires differed between stakeholder groups, so their scores are not interchangeable measures.

Table 2. Occupational therapy professional evaluation

Evaluation Domain	Design 1 ± SD	Design 2 ± SD
Clinical Suitability	5.00 ± 0.00	3.50 ± 0.71
Ergonomics	5.00 ± 0.00	3.83 ± 0.24
Safety	5.00 ± 0.00	3.83 ± 0.24
Functional Benefit	5.00 ± 0.00	3.50 ± 0.71
Potential for Use	5.00 ± 0.00	3.50 ± 0.71
Overall Mean	5.00 ± 0.00	3.63 ± 0.52

The difference between the two stakeholder groups is an important finding. End users provided a marginally higher overall rating for Design 2, whereas OT professionals provided substantially higher ratings for Design 1. This suggests that stakeholder perspectives may emphasise different characteristics when assessing an assistive device. However, explanations concerning the specific reasons for these differences should be regarded as interpretive rather than definitive because the present questionnaire did not directly measure stakeholder priorities.

c. Qualitative Feedback and Design Implications

Comments prioritized fuller hand support, grip security, changes to handle location or a knob-like configuration, and stronger cap engagement. These identify the hand–tool and tool–cap interfaces as refinement targets. Project records describe successful gripping, opening and closing of a selected fuel cap, but do not quantify torque reduction, completion time or success rates across users and vehicles. Torsional testing of material specimens in the wider project does not independently establish the benefit or safety of the complete tool.

Limitations include very few evaluation records, uncertain participant overlap across designs, pooling patient/user and relative responses, self-reported conditions, and unverified uniform exposure to both prototypes. The small design-specific samples make alpha estimates unstable and prevent broad psychometric conclusions. Future work should document recruitment and testing procedures, validate the questionnaire, and measure operating torque, grip force, completion time, slippage, durability and compatibility across cap geometries.

Conclusion

This study developed and conducted a preliminary user-centred evaluation of two 3D-printed assistive-tool concepts intended to facilitate vehicle fuel-cap opening. Both designs received generally favourable evaluations from end users, with overall mean scores of 3.93 for Design 1 and 4.04 for Design 2. Design 2 was therefore marginally more favourably rated by the end-user group.

In contrast, the four OT professionals provided a substantially higher overall rating for Design 1 (5.00) than Design 2 (3.63). Although the small professional sample prevents broad generalisation, the finding illustrates the potential value of incorporating professional rehabilitation perspectives alongside direct end-user feedback during assistive-device development.

The qualitative feedback identified improved hand support, grip security, handle configuration, and fuel-cap engagement as important priorities for subsequent design iterations. These findings suggest that both the hand–tool and tool–fuel-cap interfaces require further engineering optimisation.

Overall, the study supports the feasibility of using FDM 3D printing as a rapid prototyping approach for developing task-specific assistive technology. However, the current findings represent an early-stage evaluation and should not be interpreted as evidence of clinical effectiveness. Future research should incorporate objective measurements of required grip force and rotational torque, task completion time, unsuccessful attempts, mechanical durability, and compatibility across different fuel-cap geometries. Evaluation with a larger and more clearly defined population of users with specific hand-function limitations is also required to establish the functional effectiveness and broader applicability of the developed device.

References

Atigossou, O. L. G., Demers, M. H., Paquet, M. P., Bradet-Levesque, I., Campeau-Lecours, A., Routhier, F., & Flamand, V. H. (2025). Usability of mechanical assistive technologies for performing activities involving the upper extremities in individuals with impairments: a systematic review. *Disability and Rehabilitation: Assistive Technology*, *20*(1), 14-32.

Bulut, A. (2026). Exploring conceptual and collaborative structures in disability and rehabilitation: assistive technology-a systematic review. *Disability and Rehabilitation: Assistive Technology*, *21*(1), 3-31.

Fundarò, C., Traversoni, S., Maestri, R., Giardini, A., Ferretti, C., Casale, R., ... & Bartolo, M. (2026). A questionnaire-based exploration on therapists' perception on technology-assisted rehabilitation. *Disability and Rehabilitation: Assistive Technology*, *21*(2), 515-529.

Lingampally, P. K., Ramanathan, K. C., Shanmugam, R., Cepova, L., & Salunkhe, S. (2024). Wearable assistive rehabilitation robotic devices—A comprehensive review. *Machines*, *12*(6), 415.

Rasmussen, K. A. M., Schwartz, J. K., Aylmer, K., Keahi, C., Said, A., Ballard, D. H., & Janes, W. E. (2026). A systematic review of 3D-printed assistive technology rehabilitation interventions. *Assistive Technology*, 1-12.

Silva, J., Silva, M., Soares, B., Quintão, C., Londral, A. R., & Quaresma, C. (2025). Multi-activity 3D printed assistive technology in children: a case study. *Assistive Technology*, *37*(3), 159-164.