Exploring Foot-Operated Input for Desktop Applications

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Abstract

There is a rich history of foot-operated machinery, ranging from treadmill-powered lathes to modern vehicles. Even though early HCI research explored general-purpose foot input, most modern day research on this topic focuses either on gesture-based interaction or very specific application scenarios. Today, working on a desktop or laptop computer relies almost exclusively on users' hands, leaving their feet unoccupied. Therefore, we explore how foot-operated input devices can be incorporated in modern office workflows. We first gathered design requirements and use cases in multiple focus groups sessions. Based on our findings, we conducted a five-day diary study with twelve participants incorporating off-the-shelf footswitches with customizable functions into their usual workflows. Throughout the study, all participants continued to use the footswitches mainly for secondary tasks, such as controlling media playback or triggering shortcuts. We conclude that even simple foot-operated input devices with customizable functions can improve user experience and help users work more efficiently.

CCS Concepts

• **Human-centered computing → Empirical studies in HCI**; *Interaction devices*; *Interaction techniques.*

Keywords

foot, interaction, pedal, human-computer interaction

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Figure 1: Top: the footswitch used in our user study. It consists of three pedals, each of which triggers a key event on the host computer. Bottom: footswitch used simultaneously with keyboard and mouse.

1 Introduction

Ever since humans started using mechanical machines for work, hands were used for controlling the machines legs and feet played an important role in powering and operating those devices. For example, treadwheel cranes [10, 34] leverage the mechanical advantage of a large transmission from the treadwheel to an axle, allowing one or more people to lift large weights at building sites. Mechanical lathes, as proposed for example by Leonardo da Vinci [12, p. 512], feature a treadle-powered spring pole or flywheel. Since the industrial revolution, machinery can be powered by engines, so legs and feet could be used for operating instead of powering machines. For example, sewing machines can be turned on and off with a pedal, so the operator's hands can both be used for the actual sewing task. Foot input also plays an important role in operating vehicles, taking control of coarse input such as clutch, break, and acceleration in an automobile, rudders in airplanes, or controlling the tracks of an excavator separately. Additionally, feet can be used

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to perform secondary interaction while a user's hands are occupied, for example with effects pedals for musical instruments [53].

Human feet are capable of several degrees of freedom for movement [32, 44] and early HCI research explored how this potential could be leveraged for interaction [15, 41]. Early concepts and prototypes include sensitive surfaces and mechanical, swing-like contraptions [41], knee-operated levers [15], a foot-controlled computer mouse [42], or toe switches [56]. More current research further explored the design space for foot input ranging from mid-air gestures involving the whole lower limb [1, 16, 22, 33, 61] to small movements such as toe gestures [8, 37]. Use cases include interaction with public displays [26], accessibility [8, 54], medical applications [40], user identification [3, 23], and secondary interaction [21, 28]. Foot input can be tracked with cameras [20, 22], sensitive surfaces [3, 39], and inside-out tracking using IMUs [30] or pressure-sensitive in-soles [40].

While feet are used to operate a multitude of machines, foot input only plays a marginal role in current desktop settings. Foot-operated input devices are primarily used for three types of applications: a) recreational or health applications where foot or body movement is of interest, such as the *Wii Balance Board*[1], b) recreation of existing foot-operated instruments, such as pedals for racing games and flight simulators, or c) providing an additional input channel when both hands are already occupied, e.g., for music production or audio transcription[2].

Instead, desktop computers are operated almost exclusively by users' hands, using a mouse, keyboard, or touch screen. We wondered whether foot-operated input devices might also be useful in generic desktop computing scenarios, such as office work, creative work, software development, or web browsing. This could for example be achieved by allowing users to more easily trigger shortcuts while typing or using their mouse. Instead of – mentally and physically – switching between their primary task and secondary tasks, users could incorporate their otherwise unoccupied feet to relieve and augment their hands. In this paper, we present the results of two studies exploring how foot input could complement desktop work, following an iterative user-centred approach [6]. We conducted six focus groups to gather use cases and design ideas from 18 participants, a majority of which proposed some sort of pedal-based input device. Then, we conducted a five-day diary study, for which we provided twelve participants with off-the-shelf USB foot controllers. Compared to previous studies that mainly relied on lab studies to evaluate foot-operated input devices, we could gather deep insights into participants' usage behaviour over a longer period of time. We gathered quantitative usage data and qualitative feedback to answer the following research questions:

RQ$_1$: Which factors influence user requirements for the design of foot-operated input devices?
RQ$_2$: What are envisioned and applied use cases for foot input?
RQ$_3$: How does a foot-operated input device influence desktop work, and how is the usage perceived?

Results indicate that even though participants did not use the footswitch extensively, all reported high user experience and desired to further use the foot-operated device in the future.

[1]https://en.wikipedia.org/wiki/Wii_Balance_Board
[2]https://www.seventhstring.com/xscribe/pedals.html

2 Related Work

Foot-controlled input devices have been used and investigated since the advent of HCI research. Anecdotally, the first ever wearable computer, built by Thorp and Shannon in the 1950s [56], used foot input for interaction. English et al. [15] compared the performance of different input devices – including a knee-controlled lever mounted under the desk – for target selection in an early text manipulation system. Pearson and Weiser [41, 42] compared different technologies for tracking foot input (e.g., a light grid or a swing) and evaluated them against a computer mouse. Physiological research, for example by Roaas and Andersson [44], or Lovejoy [32], investigated the range of motion of human legs and feet. This is fundamental for designing interaction techniques for foot-operated input. Lastly, Velloso et al.'s [58] extensive literature review provides an overview of the state of the art of research on foot-based input in human-computer systems, and Matthies et al. [35, p. 10] include a table of past research on interactive foot-based devices.

Even though foot-operated input devices only play a marginal role in our everyday lives, there is a vast body of research on possible application scenarios and tracking technologies. In this section, we first cover the design space for foot-controlled input, focusing on available degrees of freedom for movement, and fundamental studies on efficiency and effectiveness. Then, we provide an overview of use cases, interaction techniques, and sensing technology for tracking foot input.

2.1 Range of Motion & Design Space

Humans are able to move their lower limbs in multiple degrees of freedom, flexing the hip, knee, and ankle joints, as well as toes, along one or two axes [32, 37, 44].

During foot interaction, users' legs can not fulfill their primary purpose of maintaining balance. Therefore, it is important to consider users' pose. Velloso et al. [58] discuss the main advantages and disadvantages of different poses in their literature review: When standing, only one foot can be used and interaction can be exhausting. In contrast, sitting allows for both feet to be used simultaneously, but their range of motion is limited and they might be occluded by a table [57]. Lastly, tracking foot input while users are walking can be challenging and interaction can lead to an interrupted walk cycle.

Foot and leg movement is less accurate in comparison to arms and hands [42]. For example, Pakkanen and Raisamo [38] found that in target selection tasks, users are significantly faster and more accurate controlling a trackball with their hands instead of their feet. Similarly, Garcia and Vu [19] found that for a text editing task, users are faster using a hand-controlled trackball compared to a foot-controlled mouse. However, performance increased faster for the foot-mouse devices compared to the trackball. Crossan et al. [11] foot tapping, in-pocket interaction and hand interaction for selecting menu entries in a mobile setting. Foot tapping was significantly slower and less accurate than both other forms of input. Furthermore, foot gestures can be fatiguing, resulting in users limiting their movements [57] and preferring gestures with an anchored heel [57, 62].

2.2 Use Cases & Interaction Techniques

Regardless of the limited range of motion and limitations caused by users' current pose, feet can still be used for interaction in certain scenarios. Examples include coarse input [38], performing gestures [11, 40, 61], or as complementary input when users' hands are occupied with another task [15, 21, 28].

Typical foot gestures include kicking [22], tapping [11], heel rotation [31], and mid-air gestures [61]. Yan et al. [61] used focus groups to elicit 31 foot gestures for social interaction. They are performed either solo or in groups of two or three people. They evaluated trackability of those gestures with a data collection study (n=18) and using the data to train a machine learning classifier. For all three gesture types, their system reached accuracy scores of above 94%.

Foot input can be leveraged to either complement or replace other input modalities. For example, Göbel et al. [21] propose combining gaze interaction with pedals to navigate a Geographic Information System. This way, users' hands are left unoccupied and can be used to perform a primary task. They evaluated their system in a follow-up study [28], in which they found that participants preferred the combination of foot and gaze input for navigation over mouse-only input. Jalaliniya et al. [24] present a system for navigating a medical image viewer with combined hand and foot gestures. Sangsuriyachot and Sugimoto [46] compared combined foot and hand input to hands-only input for a simple 3D drawing task. In a small user study (n=8), they found that participants were significantly faster using combining foot and hand input than using only their hands – albeit with a very small effect size. Similarly, Lopes et al. [31] investigated the combination of hand and foot gestures for moving and rotating virtual objects in 3D space. Results indicate that feet are more suitable for simple mode switching than for continuous input. Furthermore, examining gesture-based foot input,Velloso et al. [57] found that participants were initially challenged coordinating parallel foot and hand movements.

An important use case for foot interaction is enabling handicapped users to interact with user interfaces designed for the able-bodied. Feet can for example be used to operate prosthetics [8], for target selection [54], or for text input [55]. Tao et al. [55] propose a shoe-keyboard that allows for text input with users' feet. Springer and Siebes [54] compared a foot-controlled mouse against the hand-mouse, including handicapped and able-bodied participants. In line with previous studies [38, 42], able-bodied participants were faster and more precise using a hand-operated mouse. However, handicapped participants using the foot-mouse could achieve similar error rates as able-bodied participants with the hand-mouse [54].

Additionally, there are other, rather specific use cases. For example, Jota et al. [26] propose using foot input for interacting with the bottom region of large public displays. Janzen and Mann [25] present the *Andantephone*, a novel music instrument that is played by stepping on plates on the floor. Furthermore, tracking their feet can be used to identify and distinguish users based on their stance and balance [3].

2.3 Sensing Technology

In their literature review on foot-controlled input in HCI, Velloso et al. [58] distinguish between intrinsic, extrinsic, and mediated input. Those forms of interaction require different types of sensing technology to accurately track users' movements.

2.3.1 Intrinsic. Intrinsic input methods require inside-out tracking, leveraging sensors attached to users' feet. For example, IMUs can be used to track foot movement, allowing for gesture-based input involving the whole foot or leg [11, 22, 61]. Bend sensor can be used to detect flexion of ankle and toes [40]. Touch or pressure sensitive insoles provide fine-grained information about weight distribution and toe position. While this type of sensor is mainly used for medical purposes, such as gait or posture analysis [2, 5, 30, 43, 47] or physiotherapy [40], Müller et al. [37] show that toe movement can also be used for precise input.

One main advantage of such inside-out tracking methods is the independence of external tracking infrastructure [51]. However, they are susceptible to noise caused by accidental movement and can only sense relative movement over time.

2.3.2 Extrinsic. External tracking infrastructure allows for continuously tracking the absolute position of users' feet. This outside-in approach mostly relies on optical tracking methods, leveraging depth cameras [26] or sensitive surfaces using FTIR [3, 20] or capacitive sensors [24]. Such systems are often used for research prototypes and interactive installations, as they don't require users to wear specific hardware. However, as the tracking infrastructure can be large and expensive, and users have to be inside a pre-defined tracking area, such extrinsic approaches are limited in their practical application.

2.3.3 Mediated. Mediated input describes physical user interfaces that are manipulated by users' feet. Those include pedals and levers [21, 28], trackballs [38], and balance boards. Input is captured by built-in binary (switches) or continuous (encoders and potentiometers) sensors. This type of input is widely used to control machines and vehicles, for example as the clutch, break, and acceleration pedal in a car. In HCI research, mediated input has been used predominantly investigated as a means for secondary interaction, for example to control the viewport in 3D modelling applications [4], complementing text entry on mobile devices [14], or in combination with gaze interaction [21, 28]. Commercially available foot-controllers exist for either specific applications, such as pedals to control racing games, or balance boards – or as general-purpose devices, such as USB-connected footswitches with customizable key assignments.

2.4 Summary

As several studies have shown, foot input is significantly slower and less accurate than hand input. Therefore, it should mainly be used for simple interaction, such as mode switching, simple gestures or coarse control of a single continuous variable. However, foot input can be valuable when in comes to complementing other input modalities. For example, it can be used for concurrent secondary tasks when users' hands are occupied, or to provide an additional degree of freedom to complex interaction, such as navigating in virtual 3D space. Notably, many previous studies on foot input have focused on specific tasks and situations. Furthermore, most studies have been conducted in a lab environment, sacrificing ecological validity for more controlled conditions.

3 Focus Groups

To learn more about seated desktop work and requirements for a foot-operated device for this context, we conducted six focus groups with three participants each ($n = 18$). The 90 minutes sessions encompassed interviews, sketching, and group discussions. Together with the participants, we investigated the status quo of current work situations, ideas and wishes for computer input by foot, potential features, and requirements.

3.1 Participants

We recruited 18 participants (12 men, 5 women, 1 diverse, aged 21 to 29, $M = 24.67, SD = 2.11$) via convenience sampling and a university mailing list. Seventeen participants were students from various study subjects – digital humanities, media informatics, cultural studies and economics. One participant was a trainee teacher. Self-assessed affinity for interacting with technology was heterogeneous, with scores ranging from 2.66 to 5.11 on the six-point ATI scale [17] ($M = 4.07, SD = 0.85, \alpha = 0.89$). If eligible, students were rewarded for participation with course credit.

3.2 Procedure

First, we introduced participants to the topic and procedure. After participants gave informed consent and answered demographic/ATI questionnaires, we asked them about their current working habits and setups. Then, participants were handed sheets of paper and had ten minutes to sketch their initial ideas for foot-operated input devices that could improve their current desktop-centric workflows. These sketches were then discussed within other group members, focusing on design, tasks, and use cases. Afterwards, we handed participants four different foot controllers[3]. Participants had ten minutes to explore these devices and get an impression of how operating them felt in practice. Based on this exploratory phase, they could revise their initial design sketches and select their own favourite sketch. We concluded with interviews on design requirements, places where these devices could be used, and scenarios. During the focus group sessions, audio was recorded, and we took notes on participants' answers.

3.3 Results

We annotated qualitative feedback using MAXQDA[4]. Notes and corresponding audio-transcripts, as well as sketches were separately categorized and iteratively coded based on interview topics and similarity in context using an inductive approach, following Mayring [36].

Participants sketched a total of 45 devices. At the end of each distinct session, participants selected one favourite device of their own sketches. Among these final 18 devices, 11 are distinct from each other. The devices comprised the following components: one or more footswitches (in 11 devices), tilt pedals (6), touchpads (3), buttons (2), balance pads (2), lever (1), and a slider (1). The number of components within a single device ranges from one (3), two (4), three (4) to four (7). They were either controlled with both feet (13), or only the right foot (5).

[3]Boss FV-100 Volume Pedal, TFS-201 generic footswitch, Vox VFS-5 remote control, and a custom 3D-printed footswitch
[4]MAXQDA 2020 Analytics Pro https://www.maxqda.com/

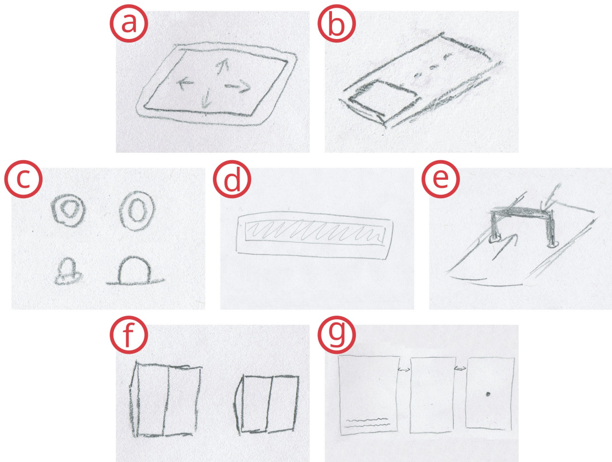

Figure 2: Examples of focus group sketches by participants, final ideas. (a) balance pad, (b) slider, (c) buttons, (d) touchpad, (e) lever, (f) pedals, (g) tilt pedals.

Input could be performed using the forefoot, leaving the heel on the ground (8), or with the whole foot on the device (5). Participants proposed binary (4), continuous (4), or gesture-based (3) input. The device should be used in parallel (2) or concurrently (2) with other input devices, such as mouse or keyboard. Haptic feedback (12) and surfaces (6), silent operation (4), and portability (10) were mentioned as additional features. Participants proposed expanding the keyboard (2) and mouse (1) – e.g., for additional shortcuts and to expand the mouse radius – as well as substituting the mouse (7), – e.g., for swiping and scrolling with one's feet while keeping the hands on the keyboard. Interestingly, all participants envisioned *mediated input* [58], with a majority of them (13/18) converging to pedal-based devices for their final ideas.

Tasks performed with a foot-operated input device include invoking shortcuts (12), scrolling (10), media control (7), and reading (1). Participants suggested that the device could be useful for transcriptions or annotations (4), text editing or formatting (4), and triggering clicks (4). Envisioned target groups include gamers (4), individuals working in the IT-sector (3), and media editors (2).

3.4 Summary

Through the focus group study, we gathered design ideas and potential use cases for foot-operated input devices. While many research papers propose foot gestures as an interaction technique [1, 8, 16, 22, 33, 37, 61], a majority of participants gravitated towards a pedal-like design. While foot-operated devices are uncommon in modern desktop scenarios, all participants had ideas on the design and use of such devices. This suggests that foot-operated input might be desirable in common desktop settings. However, a focus group provides only little insight into practical use.

4 User Study - Evaluating Foot-Operated Input

To find out to which degree users would apply envisioned interactions in their daily lives, and which additional influencing factors

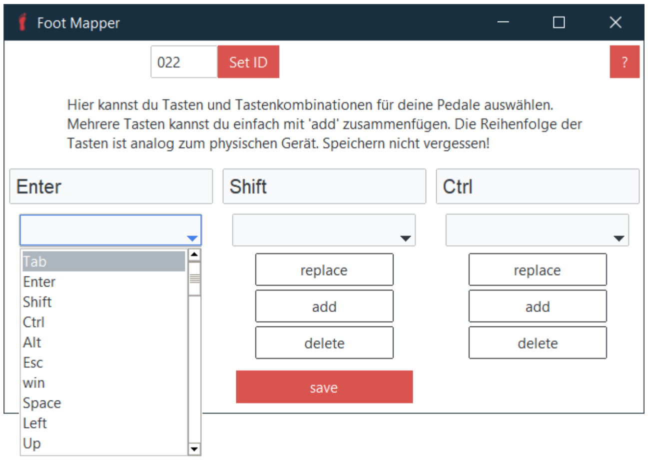

Figure 3: Graphical user interface of the software we installed on participants' computers. It allows for assigning key mappings to each of the three pedals. The UI can be accessed quickly via a system tray icon.

might come up during practical use, we conducted a five-day, in-the-wild user study with twelve participants. We provided them with an off-the-shelf USB footswitch and custom software and asked them to integrate it into their usual workflow to their own desire. To assess the potential of foot-operated input devices in office environments, we followed a mixed-methods approach [29], combining usage logs, daily questionnaires, diary entries, and post-study interviews.

4.1 Apparatus

The off-the-shelf USB footswitch[5] provided to the participants consists of three pedals with two-state switches (see Fig. 1, top), each of which triggers a key event which is sent to a computer via USB. Using the manufacturer's software, different keyboard keys and key combinations can be assigned to each pedal. However, we provided custom software (Fig. 3) which made it easier for participants to change key assignment and serves a double purpose as a data logger. Each pedal event and change in key assignments is logged by our software. Additionally, keyboard usage was logged as an aggregated number of key presses each hour. Log data was stored on participants' computers and regularly sent to a server via HTTP.

4.2 Procedure

For our five-day user study, each participant got the footswitch on Monday morning, aligning with the usual start of their workday. We informed participants about the device's functionality and the data logging procedure. We asked them to integrate the device into their usual professional and leisure work on the computer. After affirming their consent to participate, participants provided demographic information and self-assessed their affinity for interacting with technology on the ATI scale [17]. Then, the custom software for the footswitch was installed on participants' computers and we provided usage instructions.

At the end of each day, participants were asked to complete a questionnaire about their work location, usage patterns, as well as observations regarding pedal usage and other changes in their workflow. On the second and fifth (last) day, they also answered the User Experience Questionnaire (UEQ) [49]. Each study ended on Friday after the participants finished their working week. They then answered a final questionnaire and participated in a post-study interview. In the interview, we discussed their experience, effects on productivity, flow and posture, as well as how they used the device and any additional wishes.

The study was conducted following the ethical guidelines of our institution.

4.3 Participants

Through convenience sampling, we recruited twelve participants who regularly work on their computers for several hours a day, five days a week. Participation in the user study was only possible if participants were allowed to install software and connect USB devices to their computers, which is often restricted on company-owned devices.

Participants (8 women, 4 men) were between 21 and 35 years old ($M = 28.33, SD = 4.27$). Five of them worked in various academic fields, six studied media informatics or anthropology, and one was employed as a software engineer. Self-assessed affinity for interacting with technology was moderate to high with scores between 3.44 and 5.44 ($M = 4.33, SD = 0.13, \alpha = 0.85$) on the six-point ATI scale.

All participants worked at a desk or table, with eight working from home, nine at the office, four at the university, and none en route. Ten participants were usually working on a laptop, while five used desktop PCs. We asked them about their usual posture while working to determine whether using the pedals would influence their physical positioning during tasks, or might even change their habits. All participants often keep at least one foot on the ground, eight take at least one foot up on the chair, and two cross their legs.

If eligible, student participants were rewarded with course credit.

4.4 Quantitative Analysis

Each time a participant pressed and released a pedal, at least one *down* and exactly one *up* event was logged. If they held the pedal down, multiple *down* events were detected – similar to pressing and holding a character key within a text editor. We used this behaviour to distinguish between *pressing* and *holding* the pedal: if exactly one *down* event was detected before an *up* event, we classified this whole interaction as one *press*. Multiple *down* events followed by an *up* event were classified as one *hold* interaction. Over the course of five days, participants interacted with the footswitch between 180 and 2,589 times ($M = 843.8, SD = 772.8$), resulting in 10,125 total interactions (9,908 press, 217 hold).

While all participants used all three pedals, the distribution of interactions between pedals differed. The left pedal was pressed or held 4,354 times, the centre pedal 2,319 times, and the right pedal 3,452 times. Four participants pressed all four pedals roughly equally often, three participants preferred the right pedal, one participant preferred the left pedal, and the remaining participants tended to avoid either the left (2) or centre (2) pedal.

[5] https://shop.pcsensor.cn/Product-details1?product_id=1019

Table 1: Key mappings with more than 100 interactions, sorted by usage count. *n* represents the number of participants who used the key mapping at least once.

Mappings	Pressed	n	Mappings	Pressed	n
Mouse Left	1868	4	V	223	1
Alt+Tab	1507	4	Ctrl+Z	189	5
Down Arrow	1357	4	Tab	166	4
Space	715	3	Ctrl+T	157	3
Right Arrow	508	3	Ctrl+Tab	150	2
Shift+Backspace	409	1	Volume Down	146	2
R	344	1	Alt+Left	146	3
Ctrl+V	263	5	Volume Up	135	2
Ctrl+C	252	5	Ctrl+S	123	3
Next Track	242	4	Play/Pause	102	2
Enter	235	7			

Five participants increased their usage over the fist three days, followed by a decrease of usage. Four fluctuated in their use per day, three used the pedals rather consistently and two decreased their usage over the week.

Besides pedal interactions, we logged the total number of participants' keyboard key presses each hour. Of 1,440 total time slices[6], the logging software was active for 384 time slices – each corresponding to either one full hour of logging or up until the logging software was closed. Of those 384 active time slices, both footswitch and keyboard were used 247 times, solely the keyboard 115 times, and solely the footswitch once. Therefore, the footswitch was used in 64.6% of all time slices with user activity.

Mappings. Participants could change key mappings for the pedals with our custom software. We analysed changes in key mappings to get a deeper understanding of how participants used and explored the pedal. In total, new mappings were assigned to the pedals 206 times, with 80 unique mappings across all participants. Each participant changed mappings between 6 and 32 times over the course of the study ($M = 17.17, SD = 8.72$). This corresponds to 0 – 19 re-assignments per day ($M = 4.20, SD = 3.80$). Five participants assigned their most frequently used mapping on the first day of the study.

In terms of individual mappings (see Table 1), `mouse left` was triggered most frequently ($n = 1,868$), followed by `↓` (1,357) and `space` (715). Additionally, participants used common shortcut combinations, e.g. `Alt` + `Tab` (1,507), `shift` + `backspace` (409), and `Ctrl` + `v` (263). While most mappings were used by solely a subset of participants, several were notably popular, including `Enter` (7 participants) and standard shortcuts like `Ctrl` + `c` (5), `Ctrl` + `v` (5), and `Ctrl` + `z` (5). Common key assignments for *holding* include `↓` (58), `Ctrl` (26), `Alt` (23), as well as `volume up` and `mouse left` (both 18).

A schematic example of pedal usage and mapping assignments for one participant over the course of the five day study can be seen in Figure 4.

User Experience Questionnaire (UEQ). On the second and fifth (last) day of the study, participants answered the User Experience Questionnaire [49]. This way, we could capture participants' initial and more settled impressions using the footswitch. As shown in Figure 5, responses were consistently positive and showed an increase over the week across all scales.

We used paired t-tests to analyse the differences for each UEQ scale between the second and fifth day of the study. Effect sizes are reported according to Cohen [9]. While acknowledging the small sample size ($n = 12$), we found significant differences for *attractiveness* ($t(12) = -6.45, p < 0.001, d = 0.68$, *medium* effect) and *dependability* ($t(12) = -2.24, p = 0.047, d = 0.45$, *small* effect). We could not find significant differences for other scales (all $p > 0.05$).

[6]12 participants × 5 days × 24 hours

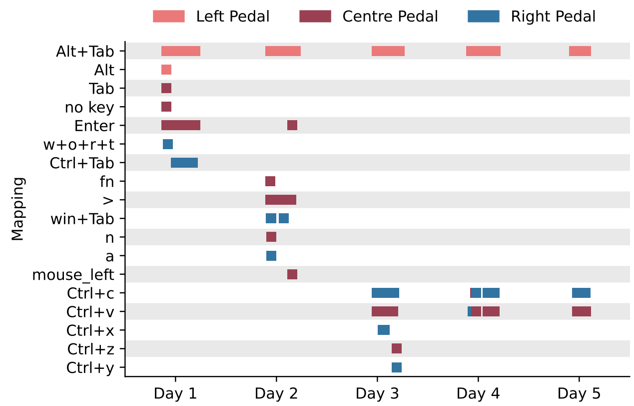

Figure 4: Pedal use of one participant over the five days of the study. The key combination *Alt + Tab* was kept assigned to the left pedal for the whole duration of the study. The other two pedals were re-mapped multiple times until converging to a final mapping.

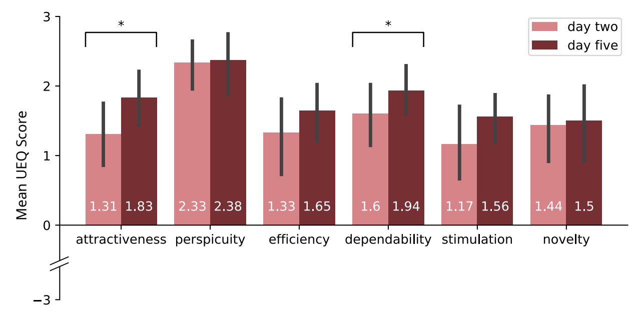

Figure 5: Comparison of the mean results of the UEQ (higher is better), combined for answers *day two* and *day five*, per scale. The error bars show the confidence interval, asterisks indicate p-values below 0.05.

4.5 Qualitative Analysis

We assessed participants' qualitative feedback with daily questionnaires and a post-study interview. In the questionnaires, participants provided information about their work location, usage patterns, and other observations. The interview focused on their overall impressions regarding the system.

Table 2: Post-study interview feedback on tasks performed with the pedals in the diary study and the number of participants performing those (n).

Task	n	Task	n
Control Media	5	Format Text	2
Navigation	4	Presentation	1
Switch Browser Tab	4	Tab Overview	1
Switch Windows	4	Trigger Browser Extension	1
Type Text	4	Scrolling	1
Confirm Input	2		

We analysed the qualitative data, consisting of answers of the online questionnaires and of the post-study interview, using QDAMiner Lite[7]. We followed the inductive iterative coding-process by Mayring [36] and based the categories of the notes and answers on the structure of the post-study interview. All coding was done by one researcher. Numbers in parentheses reflect the frequency of a specific tag and do not necessarily add up to twelve.

Input. Participants appreciated the opportunity to use *body parts* they typically do not use for input (2), and therefore *outsourcing tasks to the feet* (1). The *novel form of input* (1) and the potential for *additional functions* (1) were valued. Participants suggested that the pedals could both *replace* (4) and *expand* (3) functionalities of *keyboard* and *mouse*. Additionally, they felt that *shortcuts* could be *expanded* to (1) and *replaced* by (1) the pedals.

Using the pedals for repetitive tasks was considered both *practical* (2) and *impractical* (1). Participants valued the ability to create *custom mappings* (2), which were often selected *based on the task* (8) or occasionally depending on the *specific pedal chosen* (1). Six participants used *one mapping* consistently after testing a few on the first day. Five of them *felt like getting used to the device*. In contrast, the remaining six participants chose *several different mappings* over the week, while they had to *keep reminding themselves of the pedals*. Five of those *changed their mappings depending on the task*.

Use Cases. Over the whole duration of the study, the device was used most frequently *at the office* (38), followed by *at home* (22), *at the university* (3) and *en route* (1).

Most participants used the pedals for shortcuts including *application specific operations* (9), and *system operations* (7). The pedals were used for *common shortcuts* (8), such as *copy and paste* (2), *search and replace* (2), *undo* (2), *select all* (1) and *saving a state* (1). Five participants especially appreciated pedal-mapped shortcuts for *physically-challenging-to-type key combinations*.

The pedals were used when programming (3), *drawing* on a sketchpad (1), and *editing* media (1). Other applications include *literature research* (3), *web research* (2), as well as *data analysis* (1) and *data labelling* (1). Table 2 shows specific tasks the pedals were used for.

Posture and Ergonomics. Participants used the device wearing *socks* (10) and/or *shoes* (6). Three participants used the pedals with just *one foot*. One participant mainly used solely *one pedal*. The pedals were used in *combination* with both other *pedals* (1) and the *keyboard* (1).

Placing the feet *on a pedal* (4), was experienced as both unpleasant (2) and pleasant (1). Eight participants had to *actively locate* the pedals, while three placed their feet *next to* and four *between* the pedals, while five held them *above* the pedals. Nine participants experienced *no pain* in their feet over the week, though one described the usage as *painful* and *exhausting*, when holding their foot above a pedal during repetitive tasks. Three had to adopt *new seating positions*, which were described as *uncomfortable* by two. The sound of pressing the pedals was considered *annoying* (4).

Some participants found *new positions* to sit in (6), for example *closer to the desk* (1), or with their feet *on the pedals* (1). Eight mentioned keeping their feet more on the ground, while five criticized that *feet must be on the ground*. Five mentioned an *effect on their posture*, such as *sitting more upright*, while two described this change as *positively exhausting*. One participant mentioned using the device was *incompatible with their typical sitting position*, while one felt they could sit more *relaxed*, another noticed *no difference*.

Workflow and Efficiency. Participants self-assessed being (6) and/or remaining (9) *more in the flow* when using the pedals, thus feeling more efficient (6). These participants also felt *less mental load* while *subconsciously performing media control tasks* (5). Five wished to *further test the device*.

For two participants, the pedals *reduced task times*, two said *time spent depended on the use case*, and two noticed *no difference in task times*. One participant *changed their work habits* to integrate the pedals and enjoyed this adjustment, while another found that the *gamification of inputs led to reduced focus*.

Two participants noted that their *habits and muscle memory* from using their laptop's keyboard and touchpad *limited their footswitch usage frequency* (7). Other participants suggested a *fixed setup incorporating the pedals for consistent use* (2).

Experience. Using of the footswitch was predominantly described as *enjoyable* (9), with several participants indicating they *got used to* the device (8) or gradually developed a *sense of familiarity* (4) and being *involved* (1). Using the device was characterized as *practical* (6), *easy* (5), *intuitive* (5) and *natural* (1). Some participants found it *easy to integrate* (2) into their work routine, and liked *subconsciously* performing input (3). Others perceived the experience as *unusual* (5), an *odd motion* (2), *prototypical* (1) or even *unnatural* (1). Using the device *hands-free* was appreciated (4).

While seven participants *frequently* had to *remind themselves* to use the pedals, six needed *reminders less often*, and one had to *remember the mappings*. The self-assessed *mental load* of using the device for input was described as both *higher* (2) and *lower* (2).

The setting also played a role when using the device. Some participants chose to use the pedals in *known surroundings* (3), to avoid feeling *socially awkward* (2) and described the device as *unhandy* (1). However, four did not feel *social discomfort* using the device. One participant appreciated performing *annoying tasks in a novel way* and two liked the *novel form of input*.

Suggestions for Improvement. Two participants felt that *two pedals* would have been sufficient. Some disliked the cable connection

[7] QDAMiner Lite 3.0.6 https://provalisresearch.com/products/qualitative-data-analysis-software/freeware/

(2), and others faced an issue with the *cable getting caught underneath a pedal*, interfering with the usage (3).

Some participants expressed the need for more customization options. Suggestions included adjustable *pedal spacing* (4), a fixed *stance* (1), as well as varying *haptics* (2) and *range of motion* (3). A suggestion was made for a *smaller, single-pedal version to enhance portability* (2).

Regarding the software, participants suggested *advancing the UI* (2) and *expanding the charset* (1). For further software improvements, they recommended saving *presets* (5), adding *custom shortcuts* (3), and implementing *application sensitivity* (1).

4.6 Summary

Participants used the pedals in 64.6% of all time slices with activity. The pedals were either used to trigger specific keys or shortcuts, or held down for combined input together with the keyboard. While some participants frequently re-adjusted key assignment, others chose their mappings once and kept them throughout the study.

User experience, as supported by UEQ ratings, was considered consistently positive. Participants appreciated hands-free, concurrent interactions involving their feet, even though interacting felt unusual and participants had to remind themselves of using the pedals. Nevertheless, eight participants were interested in further using the device. Feedback on both software and hardware highlighted the requirement for more customizability. Using a foot-operated input device influenced posture when seated and working at a desktop, as the feet are required to be on the ground. Participants applied the pedals to a broad range of use cases and felt more effective and in flow while working.

5 Discussion

We followed a user-centred iterative approach to gather insights on user requirements and use cases for foot-operated input in an office scenario. Using focus groups, we gathered use cases and user requirements for foot-based interaction. In a five-day diary study, we could gather qualitative insights and quantitative usage data on how an off-the-shelf USB footswitch was applied by participants in their usual office workflow.

Previous research developed and evaluated foot input for specific use cases [21, 28, 45, 60]. In contrast, we explored how a generic and customizable device was adopted by users. This way, we could gather insights on fundamental design requirements, as well as tasks and situations users want to apply foot input to.

5.1 Requirements for Foot-Operated Input Devices

To gather design requirements for foot-operated input devices, we followed a two step process: first, we conducted focus groups to assess users' envisioned design requirements and use cases. With our diary study, we could observe users' actual behaviour. This allows us to compare envisioned and practical use cases and requirements.

During the ideation phase of our focus groups, participants sketched and discussed designs for foot-operated input devices. Interestingly, all 18 participants gravitated towards mediated input [58] with mostly pedal-like designs. Many of their ideas regarding components and form factors closely resembled commercially available footswitches, similar to the device we used in our user study. Furthermore, only minor improvements regarding the design were suggested by participants of our diary study. While many studies on foot-based interaction focus on foot gestures [1, 8, 16, 22, 33, 37, 61], our findings indicate that simple footswitches offer a feasible general-purpose interface for foot input.

In our diary study, we provided participants with footswitches comprising three individual pedals. Notably, only four of twelve participants used all three pedals roughly equally often, while four predominantly used two pedals and the remaining four only a single pedal. Therefore, our results indicate that the ideal number of pedals might depend on the current task, as well as personal preferences. However, we assume that there is an upper limit for the number of pedals that can still be controlled effectively. This is due to the pedals being operated eyes-free and human feet are better suited for coarse movements [19, 38, 42].

Several participants mentioned that when working at a desk or table, the footswitch was out of sight. Additionally, some participants reported that the footswitch kept sliding on the floor during use, which sometimes made it difficult to locate the device. Therefore, a more stable stance and haptically distinguishable switches could improve eyes-free use.

Suggestions regarding new software features include saving key mappings as presets for quick re-assignment of keys, as well as context-aware key mappings. This would allow users who often switch between applications to use the foot-operated device in multiple contexts. However, we do not know to which degree context-aware key mappings would affect mental load, learnability, and workflow.

Even though some participants mentioned feeling no social discomfort when using the pedals, they preferred using it in known surroundings. Therefore, context of use should be considered when designing foot-operated input devices.

5.2 Use Cases for Foot-Operated Input Devices

In both, focus groups and the user study, we gathered potential use cases and target groups for foot-operated input devices. We learned about participants' envisioned use cases during the focus groups, and the diary study provides insights on their practical relevance. In the following, we compare our findings to previous research.

Tasks. In the focus groups, participants proposed various tasks suitable for foot-operated input devices. These include using shortcuts, scrolling, controlling media playback, transcription and annotation, text editing, as well as mouse clicks. Among these, the task mentioned most frequently – outsourcing shortcuts to the pedals – was also frequently performed in the user study. Similarly, using pedals for media control was reflected in both studies. We therefore agree with Smus and Kostakos [52] and Saunders and Vogel [48], that music playback can be controlled with body parts other than users' hands. While they examined this in moving [52] and standing [48] scenarios, we further confirm this for seated application.

Focus group participants envisioned using foot input for repetitive tasks. However, only one participant of the diary study explicitly valued this way of using the pedals. Another participant mentioned the physical strain of keeping one foot above the pedals and therefore disliked the footswitch for this use case. Even though we can not draw conclusions due to our small dataset, the disparity between users' vision and actual usage is notable.

Additionally, we found that participants used the pedals for a variety of different tasks. Therefore, we support Buxton's [7] argument of current HCI research focusing too much on specific use cases. We propose a general-purpose device that can be used for a variety of tasks, empowering users to customize key bindings to match their current task and personal workflow.

Outsourcing Tasks to the Feet. Participants agreed on the potential of extending functions of mouse and keyboard to the feet – similar to Göbel et al.'s approach [21] of using foot input for zooming while working on other tasks. Based on our findings, we propose two approaches for integrating foot input into existing workflows: *expansion* and *substitution* of mouse and keyboard input. Both approaches were suggested in the focus groups. In the diary study, participants predominantly opted for substituting keyboard input – for example shortcuts – with pedal interactions. To allow for easier expansion of existing input methods, a deeper integration into software environments, as well as context-aware mappings of pedal functions, might be necessary.

Summary. Both the use cases envisioned during the focus groups and the use cases emerging in the field during the user study suggest that foot input can be applied effectively to a wide range of tasks. Many tasks proposed in the focus groups could also be observed in practice during the diary study. Also, design requirements derived following the focus groups reflect user requirements proposed during the diary study.

On the other hand, a number of additional applications for the footswitch emerged only during practical use. Despite restricting the use scenarios in the study, participants used the device in non-desktop related situations, indicating an even broader design space for foot-based interaction.

Those findings emphasize the need for applying both, theoretical ideation, as well as user participation and hands-on exploration to designing and developing novel forms of interaction.

5.3 Influence on Desktop Work

To address the research question regarding the pedal's influence on desktop work, we analysed participants' assessments of their efficiency and flow, as well as their ratings on the UEQ efficiency scale.

Participants felt that the device could be integrated into their workflow and enjoyed the experience. Using the pedals for media control, shortcuts, and as an extension of the keyboard helped maintaining a steady workflow. Despite some participants being challenged by locating the pedals with their feet or having to adjust their posture to keep the feet on the ground, the pedals were perceived as practical. However, given the limited time for familiarisation, some participants had to actively remind themselves of using the pedals.

Efficiency ratings on the UEQ scale were exclusively positive and increased over the course of the week. This aligns with participants' qualitative feedback, suggesting that efficiency improves as users become more familiar with the device.

Those who self-assessed as working more efficiently also reported feeling more in flow, and expressed interest in testing the device further. Participants experiencing higher flow described reduced mental load and appreciated the subconscious foot-operated input for controlling media. Consistent with Göbel et al. [21]'s findings, participants were able to interact with the footswitch while still focusing on a different primary task. They described their experience as subconscious. Most participants used the device as secondary input for tasks such as typing and performing additional inputs when drawing on a tablet. Similar to findings of previous research [18, 26, 57], we found that hand and foot input can be combined effectively. The parallel usage of our footswitch was described by study participants and is also reflected by key logs. Even though we only logged a cumulative number of key presses once per hour due to privacy, only 114 out of 349 time slices with keyboard interaction did not contain pedal presses.

Participants who frequently changed their mappings had to remind themselves a lot of using the device. In contrast, those who kept a single mapping had the feeling of getting used to the device. Interestingly, both approaches were perceived as integrable into typical work situations. As participants had to change mappings manually, we can not draw conclusions about how context-aware adaptive mappings influence users' mental load. Furthermore, the duration of five days might have been too short for participants to get fully familiar with the pedal. These observations emphasize the need for long-term examinations of such a device. Nevertheless, we suggest that the number of participants provided a first necessary basic insight into using a foot-operated input device for desktop applications.

6 Limitations and Future Work

Even though the five-day diary study could provide deep insights into participants' behaviour and experience while using the pedals, the small number of twelve participants limits generalizability of our results. Regardless of the whole week for getting used to the pedals, we observed indicators for novelty bias among participants' behaviour and feedback. Furthermore, our evaluation of the pedals' influence on users' workflow relies mainly on participants' self-assessment. While our study tested the pedals in participants' usual work environment, internal validity could be increased with a task-based A/B lab study. This way, the pedals' influence on efficiency and effectiveness could be measured quantitatively and with higher statistical power compared to our limited sample size of only twelve participants. Participants of both studies were mainly digital natives with above average affinity for technology interaction. However, we argue that this demographic represents the target group of novel forms of input. As we only logged the number of keyboard interactions once per hour for privacy reasons, we can not tell whether pedal and keyboard were used concurrently or in succession. However, in 64.6% of all active time slices with user activity, both, pedal and keyboard were used.

Lastly, futures studies should consider investigating use cases besides office work, as well as more customizability features, such as application-aware key mappings, or a more flexible hardware design.

7 Conclusion

In this work, we evaluated the potential of foot-based input for desktop applications. Previous research focused mainly on rather complex interaction techniques such as foot gestures [1, 8, 16, 22, 33, 37, 61] and/or specific use cases [28, 50, 59]. In contrast, we explored the opposite direction, using a simple footswitch and allowing users to customize key assignments to their own desire. We applied a user-centred iterative approach to turn ideas into requirements for a foot-input device. In focus groups, we explored common desktop work and how foot input could contribute to it. In a five-day user study, we observed how participants integrated an off-the-shelf footswitch into their usual office work.

User experience was high overall and slightly increased over the course of the study. As shown by usage logs and interviews, all participants could integrate the pedals into their personal workflows. Participants reported that they felt more efficient by performing secondary tasks with their feet. They were able to do so subconsciously and in parallel to other tasks. The footswitch was mainly used for simple but abstract interaction, such as substituting keyboard shortcuts. Participants reported that they interacted subconsciously and in parallel to their primary work.

Considering pedals have been part of manufacturing machines for a long time [13] and prevailed in domains such as controlling vehicles and aeroplanes [27, 41], we advocate for them to be further explored in a desktop context.

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