The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42967

Exploring Career Growth for Deaf and Hard-of-Hearing Individuals via Machining Training: A Comparative Behavioral Analysis

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EXPLORING CAREER GROWTH FOR DEAF AND HARD-OF-HEARING INDIVIDUALS VIA MACHINING TRAINING: A COMPARATIVE BEHAVIORAL ANALYSIS

1. Abstract

Overcoming challenges and transitioning from school to work is particularly problematic for individuals who are deaf or hard of hearing, presenting significant issues for both the labor market and vocational training institutions. Due to the lack of research addressing the career maturity and distinctive obstacles faced by this population, this paper endeavors to investigate performance disparities within the machining field. The specific focus is on assessing whether hearing loss may impact students' machining performance. Considering the essential human capabilities for perception in machining, especially in industrial settings, encompass a range of faculties including visualization, hearing, and tactile senses. Thus, addressing concerns related to accommodating individuals with disabilities is important, prompting inquiries into optimizing training programs and quantifying potential disparities in learning or schooling outcomes, behavioral patterns, and overall performance in future careers.

The conducted studies involved multiple participants, including hearing, deaf, and hard-of-hearing students with various machining training backgrounds. The investigation will delve into data concerning the qualities of manual machining outputs and the subject's self-rating feedback. The outcomes from this study are expected not only to allow to obtain more insights into human behavior in machining operations, but also to identify key differences between machinist trainees who exhibit no underlying hearing problems and ones who are deaf/hard of hearing. The findings of this work provide valuable takeaways concerning machinists with hearing loss, revealing little

to no effect of hearing impairment on trainee performance, alleviating concerns about potential performance weaknesses. The outcomes from this study have shown that trainee experience seems to relate directly to machining proficiency, regardless of hearing impairment.

2. Introduction

2.1 Background

Estimates from the Survey of Income and Program Participation (SIPP) indicate that fewer than 1 in 20 Americans are currently deaf or hard of hearing [1]. However, Only 53.3% of deaf people ages 25-64 were employed in 2017, compared to 75.8% of hearing people – an employment gap of 22.5% [2]. However, the statistical data also show that employment rates of deaf people increase as their educational attainment increases from 31.7% for those who did not complete a high school education. Even though the necessity of improving the education for deaf and hard-of-hearing people has been proven, among 280,000 deaf young people ages 16-24 living in the United States, fewer deaf youth have completed high school, some college, or a bachelor's degree than their hearing peers.

Based on the statistical data from National Deaf Center [2], manufacturing ranks as the most prevalent occupational field for deaf individuals. Employment rates within this sector have shown an upward trend, rising from 13.2% of the deaf population in 2014 to 15.7% in 2019. Given their strong visual communication abilities and heightened visual-spatial skills, deaf or hard of hearing individuals could offer valuable contributions in manufacturing environments that demand precision, visual quality control, and meticulous attention to detail. Furthermore, the noisy conditions typical of manufacturing settings could actually be less disruptive for deaf or hard of hearing individuals, allowing for more focused work and facilitating non-verbal communication in situations where spoken interactions may be difficult. Despite these potential advantages, obstacles in the learning experiences of deaf or hard of hearing students, particularly in the foundational stages of their education, continue to impede their progress in the field. This presents a compelling case for comprehensive and nuanced research to address these challenges.

Hearing loss stands prominently among disabilities in the United States, affecting a considerable portion of the population [3]. According to the data of the World Health Organization (WHO), it was estimated that 250 million people worldwide had hearing impairment issues in 2001 [4-6]. A number of prior works in open literature have investigated and explored a broad range of topics related to hard-of-hearing and deaf individuals. In the current open literature, numerous studies across multiple disciplines have explored topics related to hard-of-hearing groups. A study quantified the disease burden associated with older individuals' hearing impairment on the health-related quality of life [7]. Lazarus, Kelechi et al. conducted a survey that revealed a substantial positive influence from family and teachers on the career decisions of adolescents with hearing impairment [8]. Barbara Ohlenforst et al. undertook a systematic literature review to provide a thorough overview of the available evidence regarding the impact of hearing impairment on listening effort during speech comprehension [9]. Studies have indicated that individuals, particularly children, with hearing impairment often encounter increased challenges related to self-esteem. This may be attributed to communication difficulties, and the research has identified a high variability in the levels of self-esteem among this population [10]. Olaf Strelcyk et al. conducted a study utilizing an online survey that focused on the TV listening experience of individuals with hearing impairment, both with and without hearing aids [11].

Johannes Plesch et al. developed a method enabling patients to accurately and independently determine their electrical hearing thresholds, eliminating the need for an attending audiologist [12]. Lenore Holte et al. documented the characteristics of a group of hard-of-hearing children and aimed to identify individual predictor variables to unveil the barriers encountered by families during the follow-up process [13]. Michael McKee et al. underscored the additional challenges faced by hearing-impaired patients in accessing healthcare during the COVID-19 period [14]. Many researchers have delved into the differences in the education and learning outcomes for children with hearing loss [15-20]. Renee Punch et al. highlighted the school-to-work transition issue and identified a gap in research on the career maturity of this population, particularly examining how their perception of barriers might impact their future career in a broad range of occupations [21]. However, there is no evidence of prior investigations regarding training of hard-of-hearing machinists and specific barriers or difficulties they might face. In the light of lacking research, the authors have deemed the topic worth investigating for future applications in workforce development program enhancement and design.

2.2 Novelty and Motivation

This study builds upon a novel research approach proposed in the authors' recent publication [22], aimed at evaluating human performance, learning, and decision-making processes in manufacturing operations. As a comparative case study, the primary objective of this research is to revalidate the method's details and investigate the impact of varying levels of hearing impairment on machining performance and outcomes. Conducting further research with a broader participant base encompassing multiple individuals, is essential to expand upon the findings from a previously published case study. Moreover, enrolling multiple participants, including normal hearing and hard-of-hearing/deaf or hard of hearing students provides an unique opportunity for expanding the scope of studies on human behavior, learning and decision making in machining training.

3. Methodology

3.1 *Research Method - Overview*

To investigate human behavior, learning and decision making in machining training scenarios, a novel research method was proposed by the authors. It adopts a systematic approach utilizing multiple materials and methods, including collection of eye tracking and video data, observation of trainee actions, measurement of process metrics, final quality outcomes, knowledge auditing and participant surveying/self-evaluation. The experimental methodology is graphically outlined in Fig. 1.

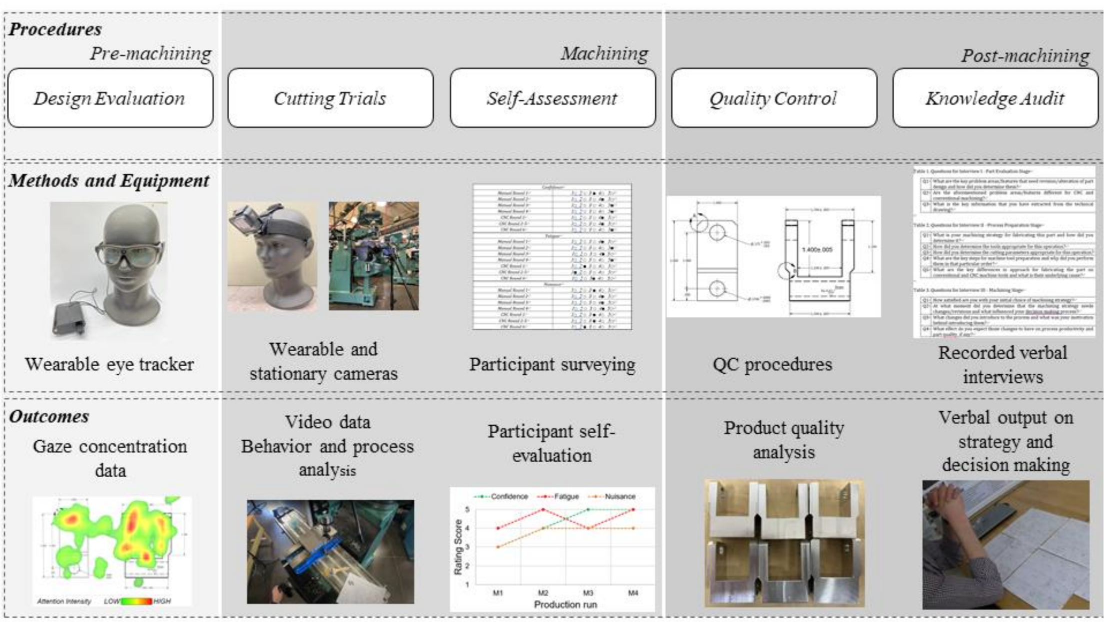


Fig. 1. *A flowchart depicting the novel research method for investigating human performance in machining training scenarios.*

As can be seen in Fig. 1, the proposed method encompasses the entirety of the production process, with key stages differentiated as pre-manufacturing, manufacturing and post-manufacturing. Here, it is noteworthy to stress that the manufacturing is repeated multiple times per participant to obtain insights into their behavior and learning processes.

For an in-depth description of procedures, methods, equipment and expected outcomes for each stage of the research, the reader is referred to a case study published by the authors [22]. Key differences between the discussed work and the previous study, including manufactured parts and participant base, are described in further detail in the following sections of this work. Please note that at the current stage, this study focused on select data collected during experimental trials, namely: 1) cutting strategy evaluation, 2) quality control outcomes, and 3) participant self-rating.

3.2 *Specimens*

All participants were commissioned to manufacture a small series of identical parts, with the part being consistent across all trials and all participants. The part design is shown in Fig. 2.

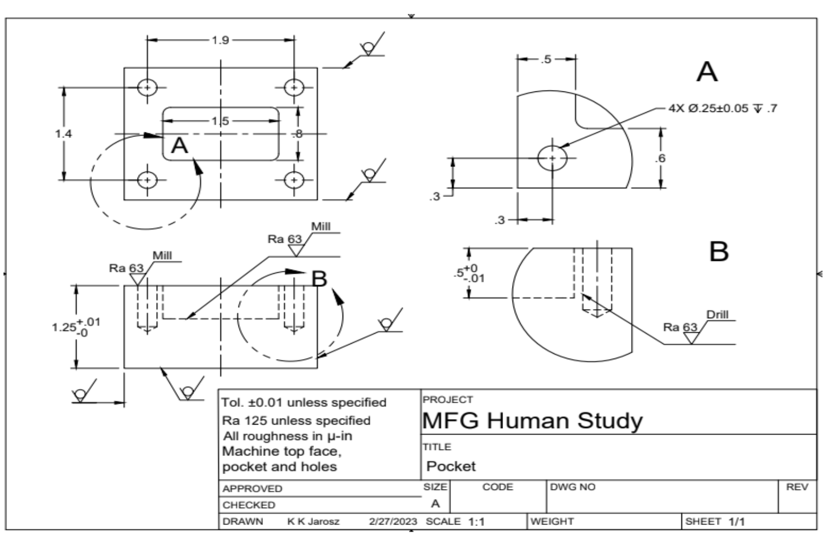


Fig. 2. *Part drawing.*

The part design adopted for this study necessitated the trainees to utilize their skills in three distinct types of machining operations, namely: face milling, pocket milling and drilling. Moreover, it required them to possess a degree of proficiency in reading technical drawings to understand the requirements that the commissioned work presented to them - namely the correct choice of datums, tooling and cutting parameters to obtain end products that satisfy quality and dimensional tolerance requirements. All dimensional tolerances were consulted with instructors working in both RIT KGCOE and NTID machine shops to ensure that the requirements posed to trainees were attainable to trainees, while still presenting a challenge to them. The participants have received three pieces of stock each in the form of previously squared blocks, with an unmachined top surface.

3.3 *Participants Selections*

Four participants (average age 21.25±2.06 years, range 19–23 years) were recruited for this study from Rochester Institute of Technology (RIT) student populations. All participants had either normal or corrected to normal vision. All participants have received formal training on machine tool operation and shop safety in their prior education. Before conducting the experimental trials, surveys concerning basic personal information, educational background and prior machining experience were administered to all participants. Prior to participation, all subjects have received a comprehensive explanation of participation requirements and experimental procedures. All human subjects have voluntarily participated in the study and have received monetary compensation as acknowledgement of their valuable contributions to this research. Personal information concerning study participants is shown in Table. 1.

__Table. 1.__ Participant information.

Participant#	1	2	3	4
Age	23	20	23	19
Gender	Male	Male	Male	Male
Vision	20/20	Glasses*[1]	20/20	20/20
Education	A.O.S.*[2]	A.O.S.*[2]	Master's	Master's
Hearing	Deaf	Hard of Hearing	-	-
Experience	1 year	2 years	6 years	1 year
*Note: 1. Corrected to normal 2. Associate of Occupational Studies (A.O.S.)				

3.4. *Cutting Strategy Analysis*

A cutting strategy analysis was performed for each participant on the basis of video data acquired in the course of the cutting trials. Here, an approach relying on showcasing the progress of the fabrication process by ordering the required cutting operations (face milling, pocket milling and drilling) in a chronological sequence for each cutting trial was employed. A graphical example of cutting strategy analysis is shown in Fig. 3.

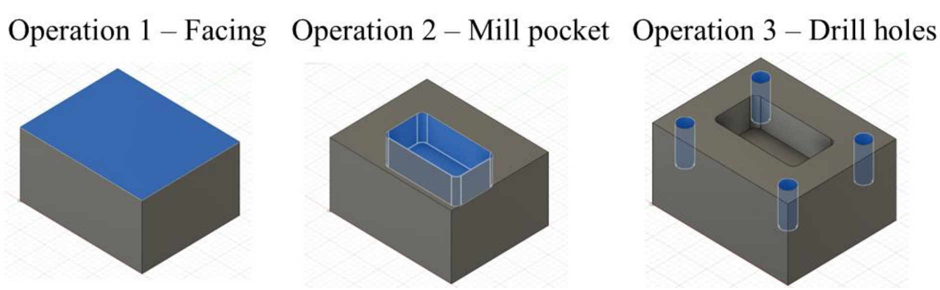


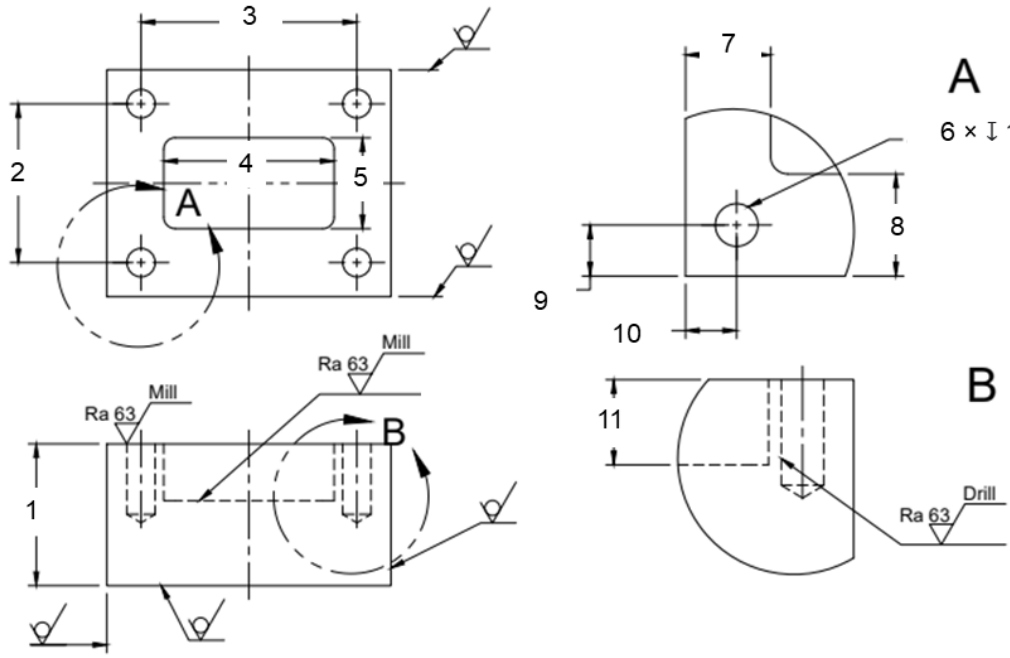
Fig. 3. *Cutting strategy illustration - progress of machining operations.*

Video data analysis and cutting strategy assessment were conducted with evaluating the following: 1) how the trainees use their procedural knowledge to solve the assigned manufacturing tasks, 2) how strategic knowledge is used to organize the production process as cutting trials progress and 3) how the subjects use their situational knowledge to overcome various problems and challenges (such as excessive chip load, extensive tool wear, unsatisfactory surface finish or dimensional tolerances), if any arise in the course of the experimental trials.

3.5. *Quality Control*

After completion of the cutting trials for all participants, quality control (QC) procedures were performed for all fabricated parts by examining all 12 characteristic workpiece dimensions specified on the technical drawing. Measurements were performed using a set of calibrated Vernier calipers and were independent of any measurements performed by participants during the course of the cutting trials. Part quality was evaluated using two distinct metrics: 1) the percentage of correct dimensions (number of actual part dimensions which were within the specified tolerance limits stated on the drawing) and the deviation of individual part dimensions from the same nominal values specified on the drawing. This method enabled a quantitative evaluation of the trainee learning process on the quality of the final product. For each part, every characteristic dimension underwent four repeated measurements. The averaged measurement results were subsequently employed in quality assessment.

After cutting trials were concluded, quality control (QC) procedures were carried out for all fabricated parts.



Dimension	1	2	3	4	5	6	7	8	9	10	11	12
Nominal Value, in	1.25	1.4	1.9	1.5	0.8	0.25	0.5	0.6	0.3	0.3	0.5	0.7
Tolerance, in	+0.01 -0	±0.01				±0.05	±0.01				+0 -0.01	±0.01

Fig. 4 *Characteristic part dimensions.*

QC consisted of performing four repeat measurements of each characteristic dimension of each individual part, as specified in Fig. 4.

The procedure consisted of performing five repeat measurements of each characteristic part dimension, as specified in Fig. 4 Averaged measurement results were used in subsequent quality control procedures.

In the first step, an overall part quality evaluation was performed by comparing each actual part dimension with nominal values specified in Fig. 4. Each actual dimension was assigned a score q_s of 0 if it did not fall within tolerance limits and a score of 1 if it met the specification. This has allowed for the calculation of part quality Q_p per equation (1). Where Q_p is part quality, %; q_s is dimension quality score (0,1) and n is the number of characteristic dimensions.

$$Q_p = \frac{\sum_{i=1}^{n} q_s}{n} \cdot 100\% \tag{1}$$

3.6. *Self-rating*

After each cutting trial was concluded with an individual participant, they were asked to complete a short self-evaluation form. This provided the trainees with an opportunity to subjectively evaluate their performance based on their personal perception of a given cutting trial. The self-rating survey was based on three metrics, employing a standardized four-point Likert scale, as outlined below:

Confidence: Rate on a scale of 1-4 how confident you were with your decision making at different stages of the process, where 1 is no confidence and 4 is absolute confidence.

Fatigue: Rate your perceived fatigue/stress/overload on a scale of 1-4, where 1 is no fatigue/discomfort and 4 is severe fatigue/discomfort.

Nuisance: Rate on a scale of 1-4 the nuisance aspect of the different stages of the process – that is, how burdensome/inconveniencing it was to perform the tasks at the various stages of the process due to their repetitiveness, where 1 is no inconvenience/nuisance and 4 is severe inconvenience/nuisance caused by the task.

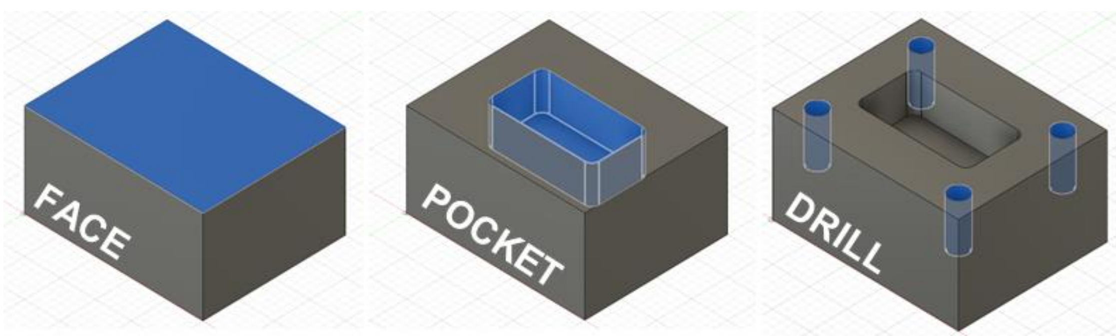
This evaluation procedure allowed for collection of data regarding self-perceived confidence and skill levels. Subsequently, a comparison of this subjective self-assessment with measurable outcomes, such as finished component quality along to investigate whether a link exists between them.

4. Results and Discussion

4.1 *Strategy*

The cutting strategy adopted by each participant was identified from collected video data and analyzed for each cutting trial. To manufacture the part, each participant had to perform three distinct operations - face milling (*F*), drilling (*D*) and pocket milling (*P*). Schematic depictions of cutting operations required to manufacture the part and their chronological order for each participant and cutting trial are shown in Table. 2.

Table. 2. *Cutting strategy of the individuals.*



Participant #	**1**	**2**	**3**	**4**
Trial 1	*F D P*	*F D P*	*F P D*	*F D P*
Trial 2	*D P F*	*F D P*	*F P D*	*F D P*
Trial 3	*F D P*	*F D P*	*F P D*	*F D P*

For all operations, the stock was mounted in a 2-jaw milling vise and parallels and none of the participants have made any changes to the workholding setup between cutting trials.

Observation of results contained in allows to easily notice that all participants have kept their cutting strategy constant between trials, with the exception of Participant 1 on Trial 2. This instance also constitutes the only case when the adopted cutting strategy can be deemed as incorrect. The participant has fabricated the pocket and hole features to dimension in reference to an unmilled top face and has subsequently machine that reference surface, effectively resulting in reduced pocket and hole depth. All other trials across all participants were performed by starting with a face milling operation, followed either by hole drilling or pocket milling. This allows the trainees to achieve correct pocket and hole depth in regards to the reference surface - in this case, the top face of the workpiece. Overall, no variability in cutting strategy was observed for individual participants between trials, with all individuals having adopted a generally correct cutting strategy, regardless of their experience level or hearing impairment. This can be attributed to a relatively straightforward geometry with features concentrated on a single face and a clear statement of reference surface on the technical drawing. These findings are contrary to the previously conducted case study [22] in which a trainee was commissioned to fabricate a more complex part geometry with no clearly stated datums and reference surfaces - in such case, far greater variability with constant variation in terms of number and order of machining operations was observed.

4.2 *Quality Control*

Quality control results for all fabricated parts are shown in Fig. 5 and Table. 3.

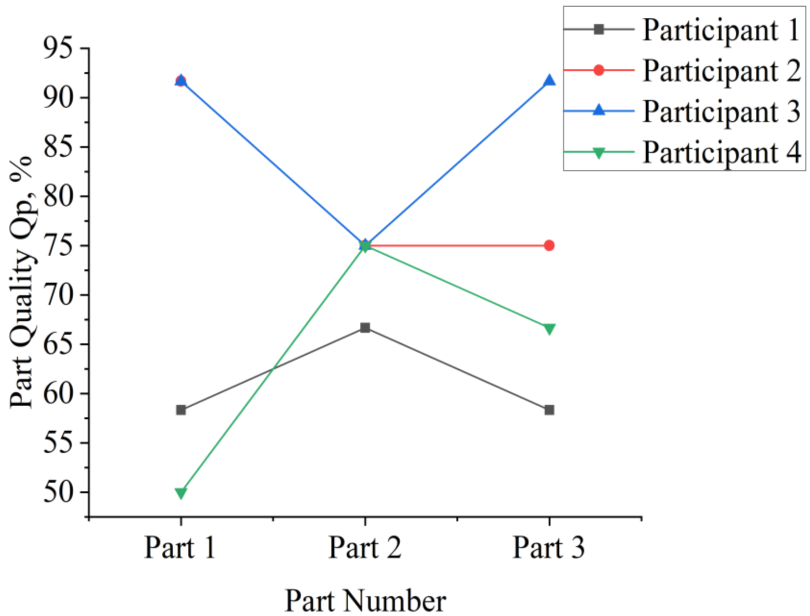


Fig. 5. *Overall part quality control results.*

Table. 3. *Quality control results - overall part quality.*

Participant #	**1**	**2**	**3**	**4**
Trial 1	58.33	91.67	91.67	50.00
Trial 2	66.67	75.00	75.00	75.00
Trial 3	58.33	75.00	91.67	66.67

From the results shown in Fig. 5 and Table. 3, it can be inferred that a notable trend can be observed for less experienced trainees - namely Participants 1 and 4. As illustrated in Fig. 5 and Table. 3, a notable trend is observed for Participants 1 and 4, showing a substantial increase in part quality between the initial and second machining trials, followed by a decline in quality during the third round. The lowest Q_p metric was noted for the first part in these instances. Conversely, Participants 2 and 3 had already attained a high-quality level (with Q_p exceeding 90%), and subsequently experienced a slight drop in quality for the second part. Participant 3 demonstrated an increase in quality during the final trial, whereas Participant 2 maintained a consistent level of quality in the last machining part.

The second step of performed quality control procedures consisted of evaluating the individual values of actual part dimensions against tolerance fields specified in the technical documentation. Here, a metric of Dimensional Accuracy A_D was employed, as specified by (2).

$$A_{Di} = \frac{D_{Ai}}{D_{Ni}};\ i\text{=1-12} \tag{2}$$

Where A_{Di} is dimensional accuracy of i-th dimension, -; D_{Ai} is i-th actual (measured) dimension, in and D_{Ni} is i-th nominal dimension, in. The results of D_A calculations for manufactured parts are depicted graphically in Fig. 6, with tolerance limits shown in a red dotted line. Hence, A_D coefficient of 1 is equal to 1:1 agreement of a measured dimension with its nominal value specified on the technical drawing.

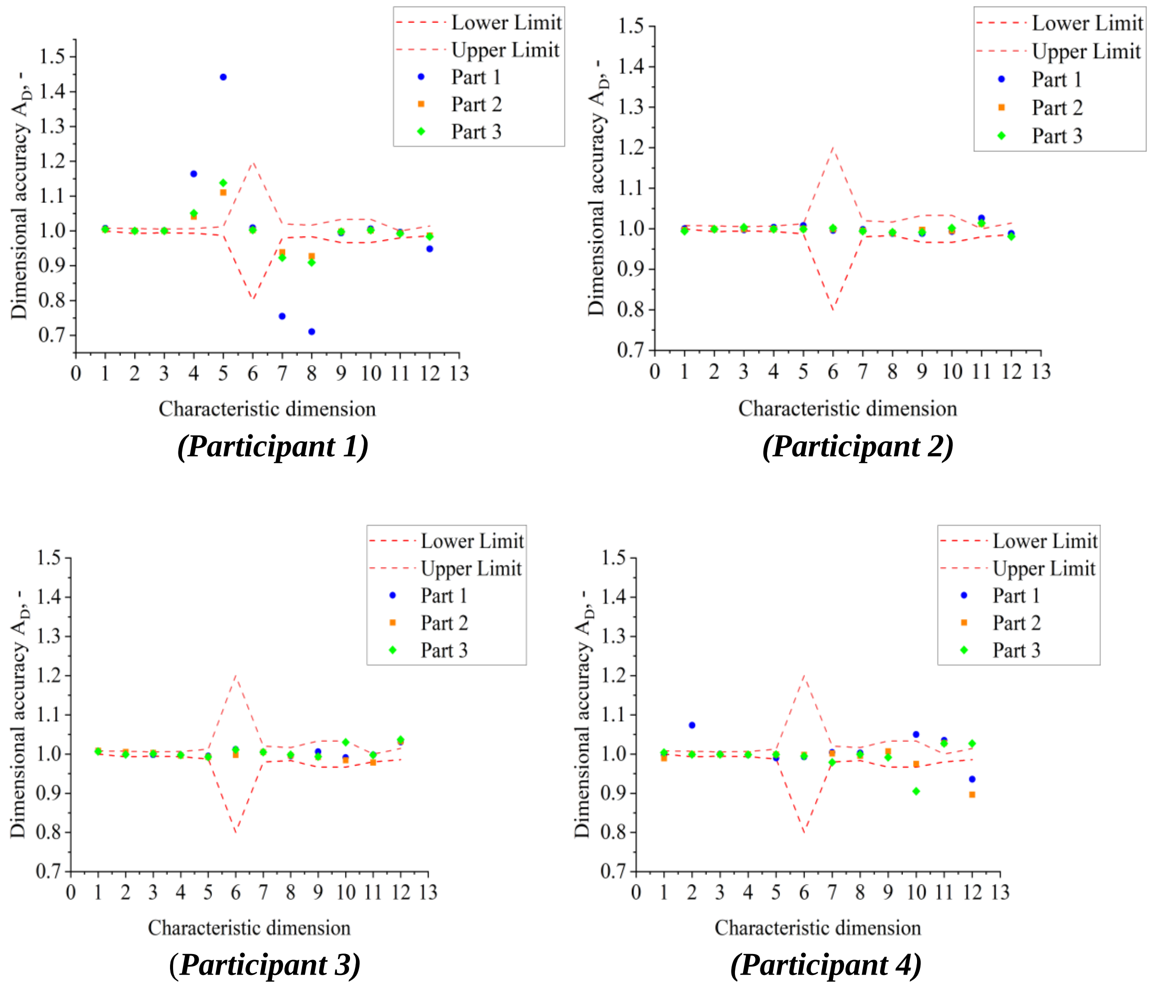


Fig. 6. *Dimensional accuracy of fabricated parts.*

Overall, analysis of results shown in Fig. 6. confirms the observations from holistic part quality evaluation. A substantial improvement in dimensional accuracy can be observed for Participant 1, with far better agreement of actual part dimensions with their nominal values. The same trend, albeit to a lesser extent in terms of initial lack of accuracy, can be observed for the second less experienced trainee - Participant 3. Moreover, a visual examination of fabricated specimens (see. Fig. 7) reveals that both inexperienced participants have effectively fabricated defective parts, despite being capable of meeting dimensional accuracy requirements on a number of characteristic dimensions. Participant 1 has fabricated the pocket feature incorrectly on all parts, whilst Participant 3 has used the wrong surface as a datum, milling the pre-machined bottom instead of the unmachined top face of the billet. This effectively violates the requirements of the technical specification, which explicitly stated to not machine the pre-machined side and bottom faces of the workpiece.

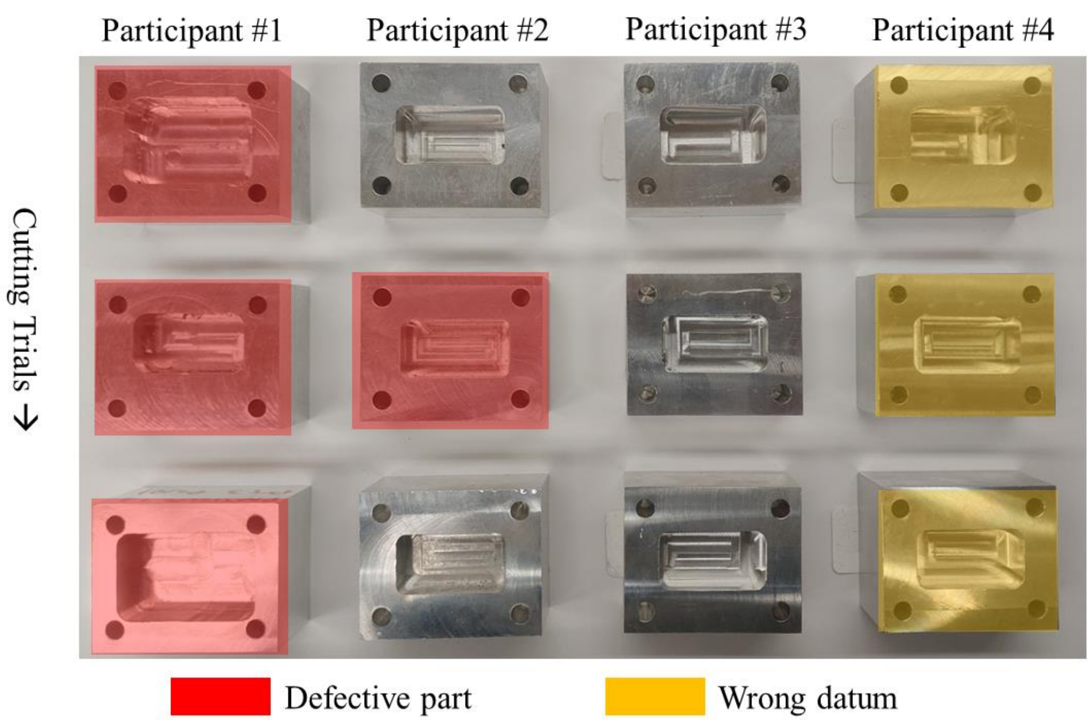


Fig. 7. *Final parts fabricated by trainees in individual cutting trials.*

For more experienced subjects (Participants 2 and 4), constant high part quality with little variation in dimensional accuracy was maintained. The only defective part was part #2 from Participant 2, where they have fabricated through holes due to a reported oversight.

4.3 *Self-rating*

All participants were asked to perform a standardized scale self-evaluation after the conclusion of each cutting trial. Analysis of the self-rating outcomes presented in

Table. **4**. reveals the following observations:

Confidence: Participants 1 and 3 exhibited comparatively lower confidence in the initial trial, which then increased in the second and third trials. Participant 2 has consistently maintained a high level of self-reported confidence throughout all three runs. Participant 4's self-rating indicated a sustained medium level of confidence.

Fatigue: Participants 1, 3, and 4 demonstrated a decreasing pattern of perceived burden in each trial, whereas Participant 2 reported a consistently low level of fatigue across all trials.

Nuisance: Participants 1, 3, and 4 exhibited a decreasing trend in perceived inconvenience across each trial, while Participant 2 consistently reported a consistently low level of nuisance throughout all trials.

Table. 4. *Post-experimental self-rating results of the participants.*

Participant #	Part #	Confidence	Fatigue	Nuisance
1	1	3	2	3
1	2	4	1	2
1	3	4	1	1
2	1	4	1	1
2	2	4	1	1
2	3	4	1	1
3	1	2	3	3
3	2	4	2	3
3	3	4	1	1
4	1	3	4	3
4	2	2	2	2
4	3	3	1	1

Note:
Confidence: 1 is no confidence and 4 is absolute confidence.
Fatigue: 1 is no fatigue/discomfort and 4 is severe fatigue/discomfort.
Nuisance: 1 is no inconvenience/nuisance and 4 is severe inconvenience/nuisance caused by the task.

Another aspect of data analysis delves into investigating possible relationships between self-reported surveying metrics and measurable performance outcomes - particularly fabricated part quality/accuracy. Employing the same analytical method as detailed in the authors' recent publication [22], the Pearson correlation coefficient (ρ) was calculated between quality outcomes (part quality Q_P, %) and self-rated confidence, fatigue, and nuisance (denoted as Y). The correlation analysis reveals that the three self-rating factors exhibit low absolute values of the correlation coefficient ($\rho < 0.3$) in this study. This outcome suggests a weak relationship between the compared variables—self-rating metrics and part quality, which is in contrast to preliminary findings from an earlier case study. A comprehensive summary of the correlation results between self-assessment and quality control is presented in Table. 5.

Table. 5. *Correlation between self-assessment metrics and part quality.*

		$\rho(Q_P, Y)$
1	**Confidence**	0.02
2	**Fatigue**	-0.28
3	**Nuisance**	-0.26
4	**Experience**	0.67
5	**Hearing Impairment**	0.16

An additional correlation analysis for two more factors (#4 - Experience and #5 - Hearing impairment) was conducted to establish whether there is a link between those participant characteristics and quality outcomes. This additional evaluation (see Fig. 8) shows that the participants’ hearing impairment did not have a significantly negative effect on their performance.

Here, it is shown that process outcomes in terms of product dimensional agreement with technical specifications are more strongly related to participant background and prior experience, regardless of hearing loss.

Table. 6. *Participants categorized by experience and hearing impairment.*

	Group #1	**Group #2**
Experience	Participant #1 & 4 (Non-experienced)	Participant #2 & 3 (Experienced)
Hearing	Participant #1 & 2 (Hearing Impairment)	Participant #3 & 4 (Normal Hearing)

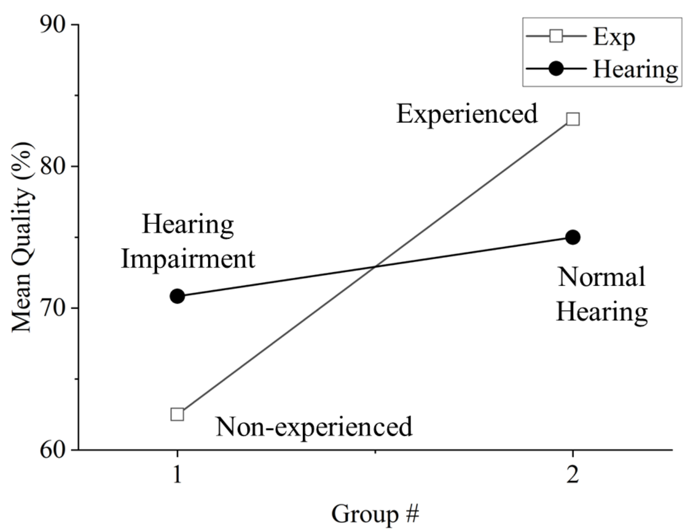


Fig. 8. *Correlation of participant experience and hearing impairment with part quality outcomes.*

As illustrated in the above graph, the 4 participants were categorized into two groups based on research factors, including background (educational and machining experience) and hearing loss. Firstly, the mean quality for the hearing impairment group is 70.83%, while the normal hearing group achieves 75%. Secondly, the mean qualities for the group with more experience and the participants with less experience are 83.34% and 62.5%, respectively. In terms of the comparison focused on hearing loss, the growth is minor (less than 5%). It's essential to note that this also incorporates the impact of other factors; for instance, one participant in the normal hearing group possesses relatively extensive cutting experience (Participant #3 has 6 years of machining experience). Within this study, the disparity in experience and background showcases a growth of over 20% in the mean quality of the completed machining parts. This suggests that the experience factor plays a more significant and influential role in shaping their performance and outputs (part qualities) in this particular case study. Given the constraint of the sample size, the conclusions drawn in this study cannot definitively be applied to a larger population or universally describe scenarios worldwide. Nevertheless, these findings offer significant evidence that concerns regarding hearing barriers may not be a determining factor in one's performance and career development. Even though students with hearing loss in this research adapted to a distinct approach to teaching and learning in machining, as facilitated by the educational system of NTID, RIT, once they acquired adequate knowledge and experience, their performance showed no significant difference compared to their normal-hearing counterparts.

Table. 7. *Total Part Yield per cutting trial for individual participants.*

Participant #	**1**	**2**	**3**	**4**
Trial 1	0.41	0.60	0.60	0.64
Trial 2	0.64	0.98	0.78	1.07
Trial 3	1.43	1.31	1.10	0.64
Note: Unit: Parts/hr				

An analysis of individual participant productivity in terms of Total Part Yield (TPY, parts/hr) is shown in Table. 7. Here, an overall trend for increasing productivity can be easily seen, with overall highest TPY values noted for the last trial. The only exception is Participant 4, who has exhibited diminished productivity for the final cutting trial. This can be attributed to numerous potential factors, including a greater concern for producing a dimensionally accurate part in the final trial or lack of strong knowledge retention from previous cutting trials. Recall that Participant 4 has self-reported a low fatigue value (1 out of 4) for this experimental trial- hence, the observed drop in productivity cannot be attributed to tiredness. Overall, there was no significant effect of hearing impairment on machinist productivity observed in the course of experimental trials.

During the cutting testing phase, it's important to note that all participants strictly adhered to safety regulations of the machine shop, wearing safety glasses during operations to prevent hazards. None of them performed incorrectly or engaged in actions that could potentially endanger themselves or others.

5. Conclusion

This comparative study involved multiple participants with varying levels of hearing impairment, diverse educational backgrounds in machining, and different cutting experiences. The investigation gathered data on cutting strategies, part quality evaluation, and self-rating scores. The principal aim of this research was to evaluate the machining performance of hard-of-hearing/deaf individuals by assessing the quality levels of finished parts and then conducting a comparison with participants from a general student population. The results suggest that experience plays a more significant role in affecting performance, with the hearing barrier causing minor differences in outputs. Hearing impairment did not significantly diminish cutting performance; differences are likely attributable to background and experience. Given the lack of research on hard-of-hearing populations, this study enhances understanding of their career development and emphasizes the impact of hearing loss on specific jobs/tasks. The findings provide valuable insights, dispelling concerns of potential performance weaknesses, and promoting awareness about the importance of understanding hearing barrier issues in the broader community.

6. Acknowledgments

The authors gratefully acknowledge the support for this work funded by the National Science Foundation Grant #NSF-ATE-2202179, titled "Improving and Modernizing Machinist Training," and the Ronald D. Dodge Memorial Faculty Grant for "Enhancing Visual Aid in Manufacturing for the Deaf Community." They also express their gratitude to NTID for generously providing facility support for the manual cutting experiments. Additionally, the authors extend sincere appreciation to all participants for their efforts, consent for data use, and active involvement in the study.

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