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EDEN ISS: HUMAN FACTORS AND SUSTAINABILITY FOR SPACE AND EARTH ANALOGUE

Authors: Dr. Irene Lia Schlacht
Politecnico di Milano/Karlsruhe Institute of Technology, Italy/Germany, irene.schlacht@mail.polimi.it

Mr. Jacopo Bernini,
Karlsruhe Institute of Technology, Germany, jacopobernini@hotmail.it

Mr. Daniel Schubert,
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany, daniel.schubert@dlr.de

Mr. Paul Zabel
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany, paul.zabel@dlr.de

Dr. Chiara Montanari,
Politecnico di Milano, Italy, chiara.montan@gmail.com

Prof. Giulio Ceppi,
Politecnico di Milano, Italy, giulio.ceppi@polimi.it

Mrs. Barbara Imhof,
LIQUIFER Systems Group, Vienna, Austria, barbara.imhof@liquifer.com

Mr. Rene Waclavicek,
Vienna University of Technology, Austria, waclavicek@hb2.tuwien.ac.at

Prof. Bernard Foing,
ESA/ESTEC, The Netherlands, bernard.foing@esa.int

Abstract

In light of upcoming plans for human Moon/Mars missions, the German Aerospace Center (DLR) and its partners are developing a greenhouse to be tested at the German Neumayer station III in Antarctica: the EDEN ISS project. One critical component of future human exploration of unknown worlds will be the supply of edible food for crewmembers. Thus, developing innovations for the cultivation of food in closed-loop systems will become essential for future missions. EDEN ISS focuses on ground demonstration of plant cultivation technologies and their application in Space. It develops safe food production for use on board the International Space Station (ISS) and for future human Space exploration vehicles and planetary outposts.

After an introduction on sustainability and the relationship with the EDEN ISS project, this paper deals with research into a range of challenges regarding the improvement and optimization of the greenhouse project's safety and performance in terms of human-system interaction. The main points are:

1. Human factors for safety and performance
2. Analysis of the main challenges of the EDEN ISS project (with a long-term focus on applicability to future Space-based plant production systems)
3. Human factors implementation proposals

The focus is on operator interaction, tackled from the human factors perspective and applying a holistic approach. In other words, the operator's needs are investigated with regard to psychological, physical, socio-cultural, environmental, and operational factors that need to be taken into account.

I. INTRODUCTION

Sustainability applied for Space

The Oxford Dictionary defines "sustainable" as "able to be upheld" (1). Sustainable is something that is able to regenerate itself in a sort of perfect equilibrium. Space is the most extreme condition where humans can live. In Space, like in other extreme environments, the isolation and the limited access to resources and service make it crucial for the system to be able to regenerate its own resources and to be able to have a sustainable and safe environment that optimizes resource use and minimizes hazards to human health (2).

Human factors and holistic approach

In these isolated conditions, the user's well-being is strictly related to the equilibrium that exists within the system, and any disruption in the balance has a direct influence on each element of the system, humans included (2, 3). In such a delicate equilibrium, the design of human factors has gained primary importance and needs to be holistic in order to support human well-being. Human factors applied with a holistic approach are meant to support human well-being from a global perspective, including psychological, socio-cultural, operational physiological, and environmental factors. For example, physical well-being as well as personal experience such as user participation in the sustainable system process are considered.

When talking about her experience living in isolated systems such as Concordia and Princess Elizabeth Station in Antarctica, one of the co-authors of this paper, Dr. Chiara Montanari, pointed out how delicate these systems are from a qualitative perspective. The external environment creates the feeling of isolation where elements such as connections to one's personal socio-cultural background become key factors in making experiences and supporting psychological well-being.

Figure 1. Chiara Montanari experiencing extreme conditions and a confined habitat (©Montanari, Princess Elisabeth, 2016)

II. THE EDEN ISS PROJECT

What is the most important factor in a self-sustainable and closed-loop system? Prof. Gene Giacomelli, a closed-loop specialist and Director of the Controlled Environment Agriculture Center (CEAC) at the University of Arizona, believes that the most important element in a closed-loop system is the production of food (4).

Figure 2. EDEN ISS laboratory at the German Aerospace Center (© Schlacht, DLR, Bremen Germany 16 March 2016)

In October 2017, the EDEN ISS consortium plans to deploy a Mobile Test Facility (MTF) in Antarctica, near the Neumayer station III, to test new technology for the production of fresh food in a closed and sustainable environment, in prevision for future Space missions.

Antarctica's Mobile Test Facility

Figure 3.: Illustrative impression of the EDEN ISS MTF. © EDEN ISS Consortium, 3D visualization: LIQUIFER Systems Group, 2015

The first objective set forward by the EDEN consortium is the construction of a Space analogue Mobile Test Facility (MTF). This MTF consists of two containers that are subdivided into three sections:

- Cold Porch: functions as an entrance room, providing storage for outdoor equipment and acts as an air buffer to limit entry of cold air.

- Service Section (SS): provides a working area for the operator and is also where the primary control, air management, thermal system, and the nutrient delivery system are located as well as the International Standard Payload Rack (ISPR) plant cultivation system.
- Future Exploration Greenhouse (FEG): where the plants will be grown (5).

Figure 4: Top view of the MTF © EDEN ISS Consortium, 3D visualization: LIQUIFER Systems Group, 2015

Figure 5: Frontal view of SS, entrance of FEG and FEG interior. © EDEN ISS Consortium, 3D visualization: LIQUIFER Systems Group, 2015

The MTF will be 20 feet high and placed at 300 meters from the Neumayer station III (6). Figure 4 shows a top view of the layout.

Objectives of the EDEN project

This project approach involves both the concept of sustainability and holistic design for Space applications.

One objective of the EDEN ISS project is to verify the impact of fresh food on the psycho-physiological performance and well-being of the crew in long-term isolation. To achieve these objectives, the operator inside the facility will be living in isolation in Antarctica for one year, cultivating a variety of vegetables to be consumed by the Neumayer III crew. Due to the long isolation in this extreme environment, sustainability and a holistic approach to human factors design are of utmost importance.

In this paper, implementations of the EDEN ISS project are described that address the human factors design of the sustainable system as part of a holistic approach. The implementations are divided into:

- EDEN ISS: psychological and socio-cultural factors
- EDEN ISS: operational physiological and environmental factors

Plan for analyzing the impact of fresh crops on the crew

To analyze the impact of fresh food production and consumption on performance and well-being, the "human factors debriefing procedure" (developed by Schlacht) and the questionnaire "Profile of Mood States" have been proposed by Schlacht and Bernini to be used by the Neumayer station III crew during the 2017 mission ([7]). The "human factors debriefing" will investigate the effect of the consumption and production of fresh crops in a holistic way. The "Profile of Mood States" will assess the changes in morale the crew might exhibit while consuming fresh food.

III. EDEN ISS: PSYCHOLOGICAL AND SOCIO-CULTURAL FACTORS

The EDEN ISS study will investigate the hypothesis that "fresh crops are not only beneficial for human physiological health, but also have a positive impact on crew psychological and socio-cultural well-being" (8 p. 2). Psychological and socio-cultural well-being can be influenced on several levels to increase the crew's quality of life; for example by adding the qualitative dimension of serving sustainable fresh food produced locally to the socio-cultural ritual of a meal.

Psychological benefit of plants

Considering the current and future psychological dynamics of Space travel (9), “there is mounting evidence from various academic disciplines that nature, and experiences with nature have a restorative impact” (10), including stress reduction, anger reduction, increasing of attention, positive mood, and an overall restoration in energy and well-being (11). In this second case, interaction may either be active or passive. Active interaction will be for the people who need to work and get in contact with the fresh crops, and passive interaction will be for the crew if they have visual access to the plants. For example, inside the ISS, the “Biomass Production System for Education” is a system where plants are grown, but they are not easily visible to the crew. Improving the visibility of the plants could provide psychological benefits to the entire crew (Figure 1.) (12). In the EDEN ISS, the crew will operate in the main station while the vegetables will be grown inside a separate module by an operator. In this case, the impact will be beneficial in particular for the operator of the EDEN ISS module and for the other crew members during meals. To extend this benefit, it may be possible to even bring some crops inside Neumayer III or to invite the crew members to visit or cooperate inside the module.

In conclusion, the production of fresh crops is psychologically beneficial because it provides contact with plants.

Figure 6. “Biomass Production System for Education” used for testing, for future deployment onboard ISS. (© Schlacht, EDEN ISS laboratory, DLR, Bremen 2016)

Socio-cultural benefits of sustainable quality

Apart from psychological benefits, socio-cultural aspects are also very important in isolated and extreme environments. In the EDEN ISS project, these factors will be approached as part of the application of the principle of sustainable quality.

Sustainable quality addresses socio-cultural factors associated with a sustainable system. Sustainable quality refers to psychological and socio-cultural qualities of a sustainable product or a service produced locally. This means, for example, having the product or service connected to a cultural experience related to the local background.

The concept was developed by the Slow Food organization. In particular, the EDEN ISS project addresses this quality in two complementary areas:

- Generating a social good given by the cultural diversity of local food production;
- Supporting the quality of experience as a key element of sustainability (13 p. 4).

In the EDEN ISS project, the food will be produced locally, experienced culturally, and consumed by the producers.

The EDEN ISS project (Figure 2) is an explicatory project aimed at understanding how sustainability needs to be addressed – following the Slow Food approach – as a quality in a Space station system and also in food production on Earth. In particular, the type of food selected to be produced addresses not only the likelihood that the plants will grow healthily in such an isolated system and will support the physical well-being of the crew, but is also based on cultural values.

In particular, during the first test mission in Antarctica, Paul Zabel, the “astronaut” who will be the main food producer, had the opportunity to influence the selection of food to be grown. In particular, he asked for the presence of dill in order to create pickled cucumbers. This factor will allow him to experience a cultural quality, as it will link his well-being to experience related to his socio-cultural background. As he explained: *“Cucumbers were on the list of target crops from the beginning because they perfectly fit our pick-and-eat strategy. I did not influence the choice. However, I am very happy that cucumbers are on the list because I really like cucumbers. My taste for cucumbers might come from the cultural background of my home town, which is famous for growing cucumbers on fields to make a wide variety of pickled cucumbers in jars (14). I will try some of the recipes (15) with the cucumbers I grow in Antarctica. Furthermore, my grandparents always grow cucumbers in their small garden greenhouse and I love to eat cucumbers directly from the plants on hot summer days.*

However, I influenced the choice of having dill among the herbs because dill is an essential ingredient for most of the pickled cucumber recipes.”

Color variety against depression

Apart from cucumbers and dill, the production of tomatoes is currently also being tested in the EDEN

ISS project (Figure 3) together with other vegetables. The tomatoes are not only to be grown as a source of fresh vitamins, but will also bring to the meal ritual a red element, which is a color that has a warming effect and psychologically helps to fight depression caused by monotony because it adds color variety to the meal (16, 17, 18). Indeed, color variability is a relevant element for psychological support, as reported in a survey by six of seven astronauts interviewed (19). In this perspective, the use of differently colored flexible LED strips to optimize plant growth also adds color variability and may also improve the crew's psychological well-being (Figure 6 and 7).

Figure 7. Using flexible LED strips for cultivation of Microtina and Vreudgenhil tomato plants from the EDEN ISS laboratory, German Aerospace Center (© Schlacht, DLR, Bremen Germany 16 March 2016)

IV. OPERATIONAL, PHYSIOLOGICAL AND ENVIRONMENTAL FACTORS

This section focuses on the optimization of operational and physiological human factors at the Mobile Test Facility (MTF). This optimization has been achieved with a holistic study of the usability weaknesses and strengths reported in Bernini (2016) (20) and is based on:

- Human needs pyramids by Maslow (1943),
- Integrated Design Process by Dr. Schlacht (2012),
- DIN standards,
- Neumayer station III safety guidelines,
- and input from field specialists and the future operator Paul Zabel.

In the Cold Porch, it can be seen that mainly the safety and physiological aspects have been improved. Safety was optimized by ensuring that the safety equipment included a smoke detector under the raised floor and a CO_2 fire extinguisher. These two components will be helpful in case of a fire by ensuring earlier detection and giving the operator the chance to extinguish a fire using an inert gas to ensure minimal damage, if any, to the electronic equipment. The heater and the body waste management system help to optimize the physiological factors. The body waste management system enables the user to attend to his needs of urinating and defecating without having to go back to the Neumayer station III, which can present a safety risk due to the extreme environment.

In the service section, the implemented designs improve the overall usability of the section as well as its habitability. The window has been set at a height that ensures that multiple users can see through it without problems, both while standing and while sitting. Positioning the sink right underneath the window will allow more space to sit under the window, also with colleagues, if necessary.

The adjustable workbench height will allow multiple users to set it at the height they find most comfortable. Additionally, if the optimal option of a glass door or a porthole between the service section and the Future Exploration Greenhouse (FEG) is realized, this will allow different benefits as a result of viewing the crops directly. These benefits include:

- psychological benefit against the monotonous environment

- enhancement of safety and performance as the operator can constantly see the crops without entering the FEG, for example if the electronic system does not work properly in case of fire or if chemicals need to be used that may be dangerous for the user's health. Moreover, user access to the plants can also alter the optimal environmental settings for the plants to grow in.

In the FEG, the overall safety was improved by ensuring easy access to the emergency exit, and, as in the cold porch and service section, fire prevention was improved with a smoke detector and a fire extinguisher.

Finally, again in the FEG, the window should be orientated such as to show the view of the Neumayer station III (the safe haven) in order to create a feeling of safety against isolation and also to allow possible visual signals to be exchanged with the station.

The exterior's safety was also improved by ensuring that the height of the safety railing accounts for snow build-up, and by allowing the operator to attach himself with a harness to a steel cable to prevent him from slipping and falling in case of high winds.

Visualization of the Implementations

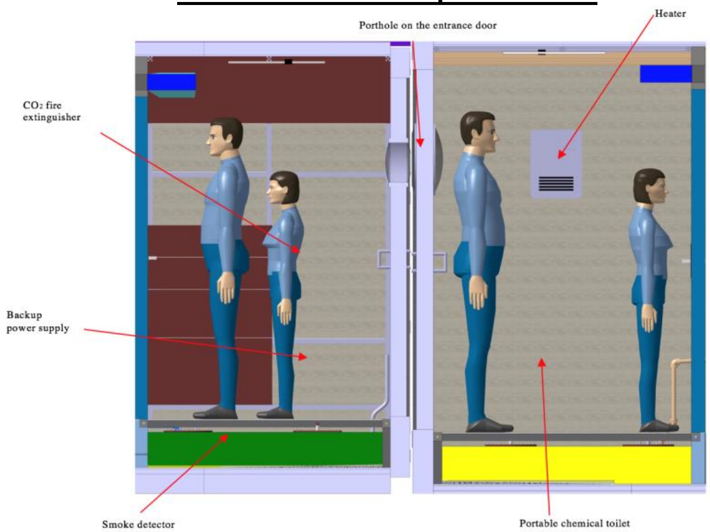

Figure 8 Human Factors implementations for each section of the MTF.

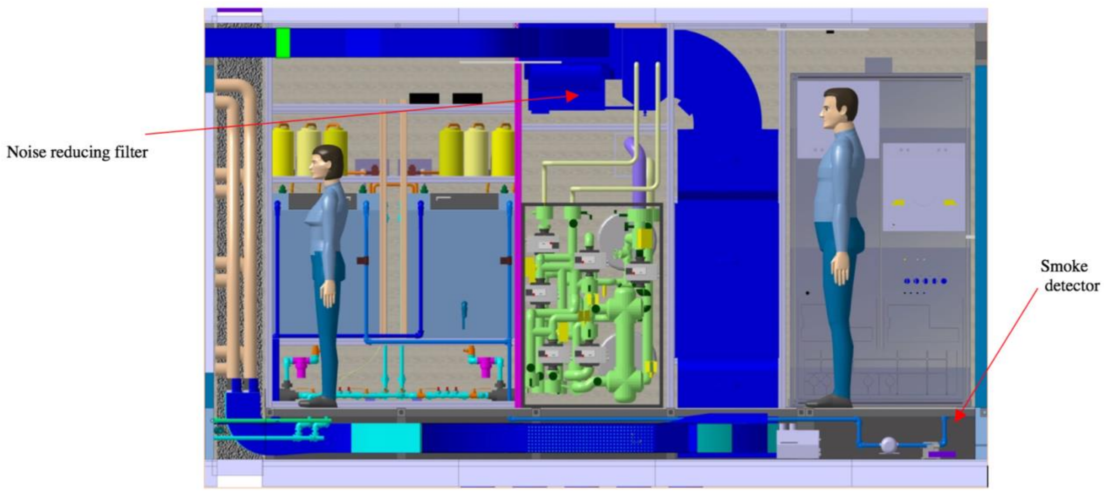

Figure 9: Side views of the cold porch with implementations

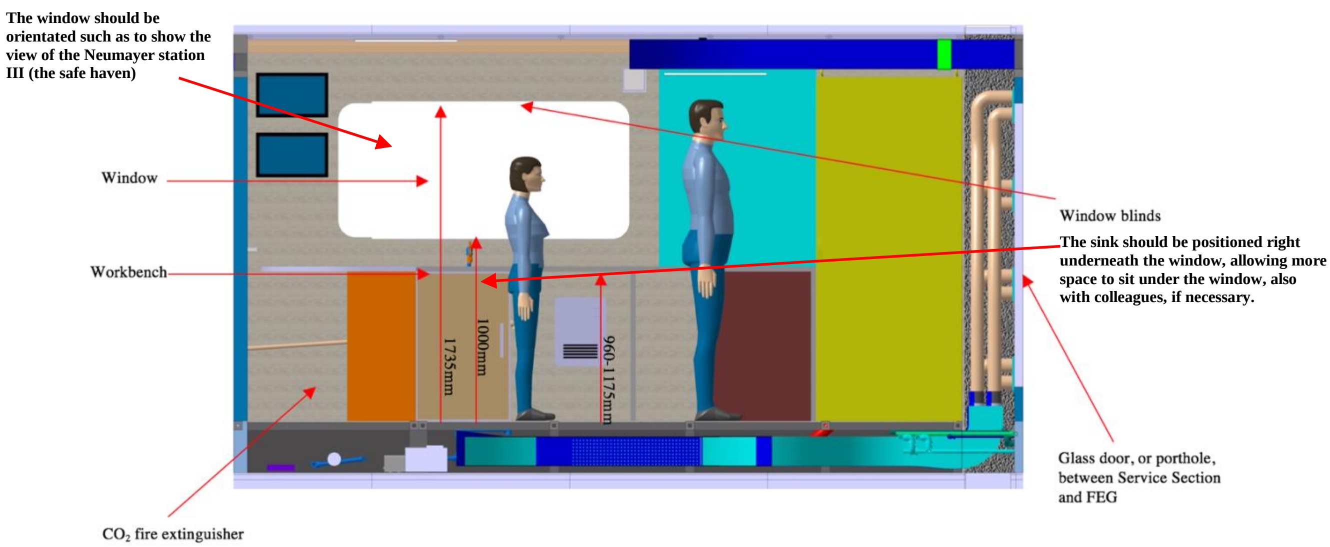

Figure 10: Side view of the service section with implementations

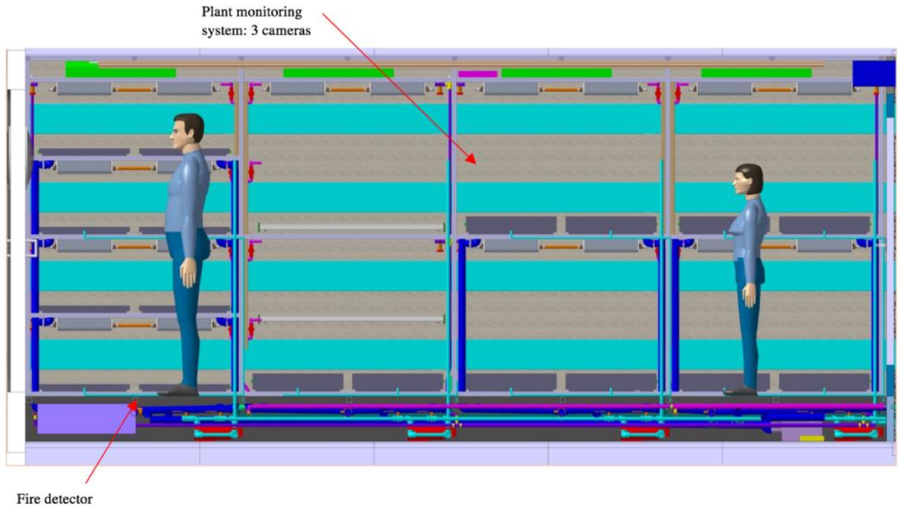

Figure 11: Side view of the future exploration greenhouse with implementations

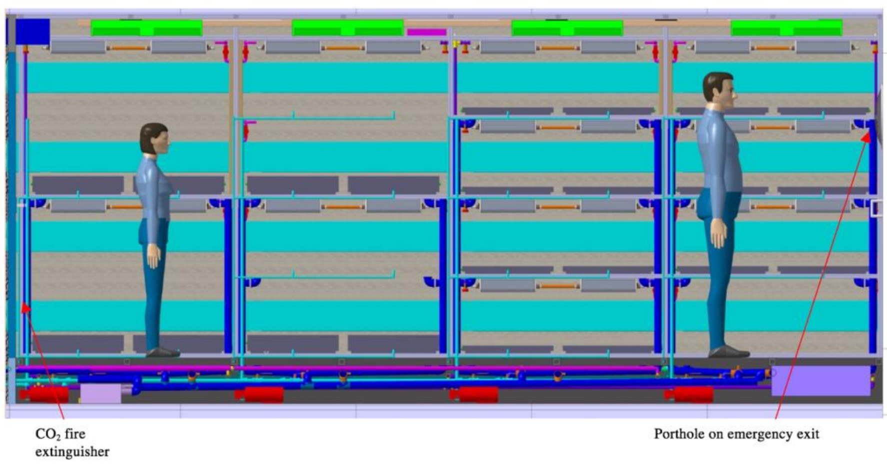

Figure 12: Side view of the future exploration greenhouse with implementations

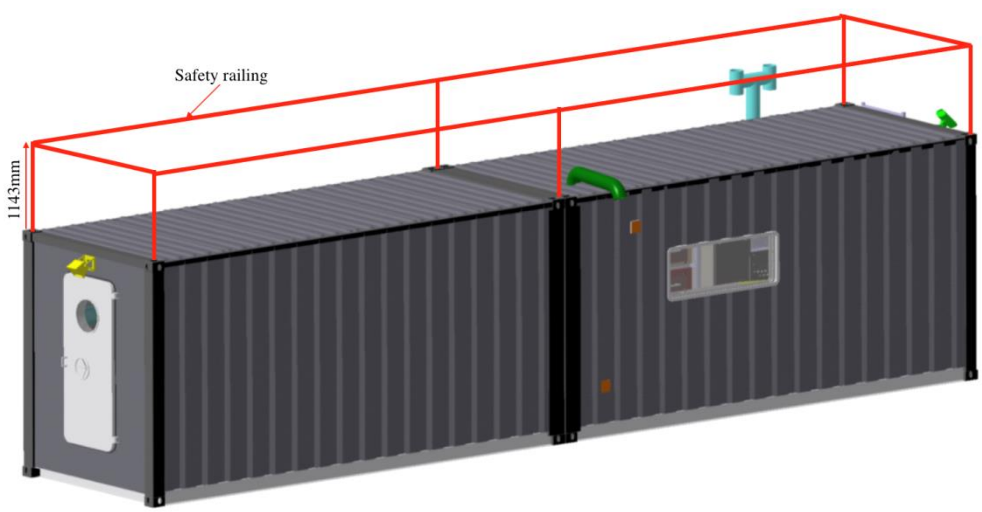

Figure 13: Exterior of the MTF with implementations

V. CONCLUSION

This paper addressed considerations of the EDEN ISS project related to psychological, socio-cultural, operational, physiological, and environmental aspects following a holistic approach.

Specific implementations were presented here to increase the overall human-centered design of the project. To develop the implementation, the usability of each element has been considered and improved to support the users' safety and well-being on the basis of a holistic approach to the design. Additionally, this design helps the operator fulfill his needs according to Maslow's hierarchy of needs (1943). Finally, it can be reported that the habitability factors according to Schlacht's Integrated Design Process (2012) have also been enhanced, thus ensuring a more comfortable design.

The implemented designs still follow the applicable guidelines and standards while ensuring a more ergonomic and habitable design. This will allow the operator to work in a more user-friendly and comfortable environment, which should help fight the stress and anxiety caused by the extreme environment of Antarctica. For this reason, his performance should increase.

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