Received: 2 January 2020 | Revised: 24 September 2020 | Accepted: 25 September 2020
DOI: 10.1002/eng2.12309

RESEARCH ARTICLE

WILEY

Environmental impact and performance assessment of a new Zigbee-based shotgun training system

Boubaker Ben Ali[1,2] | **Chawki Fraj**[2,3] | **Olfa Oueslati**[3] | **Éric Dugas**[1]

[1]LACES 7437, University of Bordeaux, Bordeaux, France
[2]ECOTIDI-UR16ES10, Virtual University of Tunis, Tunis, Tunisia
[3]University of Manouba, Manouba, Tunisia

Correspondence
Boubaker Ben Ali, LACES 7437, University of Bordeaux, Bordeaux, France.
Email: boubaker_benali@yahoo.fr

Abstract
Only a few research works have studied the risks involving young athletes in shooting activities such as noise and risk of projectile impact. Besides, limited studies have explored the environmental concerns caused by remaining projectile fragments scattered into the environment. In recent years, there has been an increasing interest in integrating computing, modeling, and IoT-based applications and used connected add-ons (e.g., steams Virtual Reality VR, virtual guns, and game controllers) in sports activities displayed in virtual reality gaming environments. The aim of this paper is, first, to present a multi-aspect Zigbee-based protocol system used to assess and to improve reaction time and score prediction abilities of Shotgun sports practitioners indoor and outdoor. Second, B-percept would be presented as a training solution to reduce environmental scattered wastes of used Clays. After 8 weeks of training, there was significant improvement ($p < .001$) of participants' reaction time by using the B-percept simulator. In addition, improvement in real clay shotgun results ($p < .0002$) but it was difficult to correctly predict more than 60% of correct scores after the test. The results of this study encourage continuing to improve the B-percept to use wireless moving targets for training purposes.

KEYWORDS
B-percept, environment, shotguns sports training

1 | INTRODUCTION

Research related to Human Behavior Modeling has increased and widely spread during the last few decades in medicine, engineering, as well as in military and sports activities. Several studies have indeed been carried out to find technical solutions to improve professionals' decision-making in sophisticated situations that need speed and accurate responses.[1,3] The behavior modeling aims to overcome the constraining effects of external environmental or human factors[4] by creating

Special Issue Note: This paper is part of the Special Issue "Selected extended papers from the 3rd International Conference in Engineering Applications 2019 (ICEA19)."
The preliminary findings[42] were presented at the 3rd International Conference in Engineering Applications—ICEA 2019, 8-11 July 2019, in Azores, Portugal.

new artificial conditions to help optimizing adequate responses to environmental stimuli.[5] However, the main problem with some modeling applications is to be disconnected from reality concerns and daily experienced situations. Accordingly, questions have been raised by specialists about the ecological validity of these modeling processes.[6] There is hence a growing need to have studies closely related to ergonomics, engineering psychology, and cognitive engineering.[7] Indeed, at its beginning the computer-aided modeling consisted to place subjects in front of computer screens where visual stimuli are represented by figurative items (ie, letters, crosses, geometric shapes) and combined with distractors; the computer tools (screen/keyboard) have improved the possibilities of testing and enhancing subject performances through protocols needing to press mouse keys or a keyboard as responses to stimuli.[8] However, more recent attention has focused on the ecological validity of the in vivo interaction between the tested subject and its surroundings to fill the research gap of working on a dynamic-body interaction with the world. Thus, literature has emerged that integrating computing and IoT-based applications into modeling process,[9,10] while keeping a close link with their application in the real world provides not only a quantitative forecast but also could explain the nature of the problem and the phenomena observed.[11] Li, Huang,[4] Anderson, Betts[12] show up that simulation platforms can help to quickly study human performance in various operations (eg, regular training, work, and competition), outcomes of which are then verified in a real environment. Indeed, this could significantly improve task efficiency and human performance and/or prevents accidents by minimizing errors and reducing unnecessary personal damage.

More recently, there has been an increasing interest in modeling sports activity. Though, little research focuses on shotgun competition with flying clay targets[13,14] except for studies concerning biathlon shooting.[15] Formerly, clay pigeon shooting was originally developed as a training aid and a substitute for shooting live quarry[16] and since the invention of this sport it has evolved, and now there exist several branches of clay pigeon shooting and some of these are included in competitions at the Olympic Games. The frequently attracted tens of thousands of spectators and shotgun practitioners over the last decades renewed researchers' interest in many risks involving athletes such as noise of shooting or risk of projectiles impact. Additionally, there are few pieces of research interested in the environmental pollution caused by remaining projectile fragments scattered in nature and recognized as a serious worldwide public health concern. Davidson, Thomson[17] stated that the spent lead shot is rarely removed from the environment, except at some large shooting ranges. Almost 20 thousand tons of lead shot are added each year to wetlands and dry land areas and at least half of these are from dry land hunting and clay target shooting sport.[18]

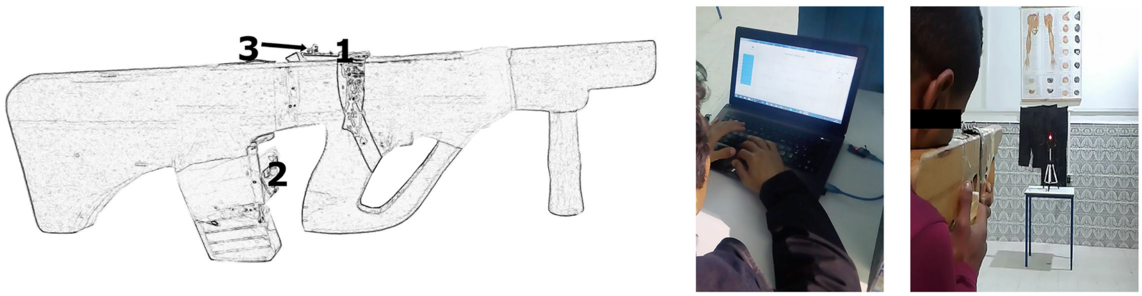
Based on recent research statements, the main contributions of this work are as follows:

1. Review the recent research in the fields of Human-Computer interaction dealing with virtual simulators and prototype engineering introduced for better training the shotgun sports technics for young practitioners.
2. To assess the efficacy, reliability, and utility of the B-percept system as a multi-aspect Zigbee-based protocol used to assess and improve the reaction time and score prediction abilities of young practitioners in shotgun sport indoor and outdoor.

1.1 Related works

Modern competitive shooting is a challenging test of the human perceptual and motor systems.[14] Shooting sports need a very high speed of action and decision. Shooting competitions involve precise and rapid movements coordinated using a careful mixture of planning and reactions. Clay pigeon sport shooting is a competition in which an athlete shoots a clay disc launched into the air. Accordingly, it depends on the skill of the participant, his expertness, and his level of trainability to perceive the target, to focus, and predict its trajectory in the sky, then, to shoot it successfully.[2] Consequently, in shotgun sports practice, many variables can erratically change like the distance to the target which can become greater, the clay can move faster or slower through irregular trajectories (eg, launcher errors or irregular wind effect).

Monfared, Tenenbaum[19] have stated that shooters with different levels of skill use visual feedback to detect performance errors and to anticipate outcomes. He settled that skilled groups have a better ability to use non-visual information to take a decision. Besides, multiple studies have demonstrated that shooting expertise is attained by intensive repetitions which help to reduce movement during shooting phases[20-22] and that experts keep their weapon more stable and have more advanced awareness and cognitive abilities to detect performance errors than less skilled.[23-25] Furthermore, practical experience has shown that it was very difficult to teach someone to become proficient in a shotgun sport without close support from coaches who are quite rare and also need time and experience to be able to identify errors, especially if the shot is missed since the mean duration from the appearance of the target in the rifle ring to shooting is reported as being only 100 milliseconds,[26] which may require special consideration of shooters training in highly demanding situations when full access to sensory information is needed.



(A) (B) (C)

FIGURE 1 (A) Schematic drawings of B-percept shotgun simulator[1] RF transceivers board[2] Tactile Switch[3] Electroluminescent diod (LED). (B) Laptop using B-percept java software. (C) Testing situation

Over the past decade, there has been a rapid development of video games on computers and smart phones. Designers worked on the development of virtual reality gaming environments and used connected add-ons (eg, steams VR, virtual guns, Joystick simulators and game controllers) in order to provide more realism to the virtual games.[16,27] Several researchers proposed using a virtual reality environment for shooters training.[15,17,27,28] However, experiments showed that there is a disconnection in the interaction between the physical and virtual elements which would affect the efficiency of any training system looking for the development of motor skills.

Presently, there are several clay pigeon simulators on the market and approximately 2588 shotgun sports-related patents published in Google patents up to January 2020 (eg, accessed January 2020). However, most of these devices were exclusively conceived to be used in shooting ranges. Thus, Harvey, Selmanovic[16] stated that only manufacturer information provides context to the ability of these systems to improve task performance (further information: SimHunt Shooting, Winchester Total Recoil, Dry Fire, Shot Pro 2000[16]). Nevertheless, few studies have investigated the outcomes of shotguns sport on simple and complex reaction time, performance expectancy, and self-efficacy with a scientific purpose. In addition, a few research studies have been published about the negative impact of shotgun sports practice on the environment.[18] Accordingly, this paper attempts to investigate and bridge a gap by using a wireless and easy to use system looking to reduce spending Clay pigeon targets.

1.2 | B-percept simulator system

B-percept[29] (Figure 1) is a Zigbee-based (IEEE 802.15.4) personal area network system used to measure reaction time by transferring pre-programmed simple or randomized light and sound signals through low power-demanding devices (XBee S2)[30] for which subject have to react. "B-percept system" is conceived by a young research team for a non-profit-scientific use. It is a multi-aspect Zigbee-based protocol system used to assess and to improve reaction time in many domains (eg, sports, military, gaming, driving safety, teaching performance assess). This system aims to record, transmit, and analyze data from various situations requiring precision and reliable measurements of simple and complex reaction time.

Thus, B-percept is basically safe (eg, low voltage board no interfacing circuitry to 3.3 V devices needed) and it is easy to install on any kind of shotgun (ie, for professional elites, amateurs, and experimentals). Additionally, B-percept signals have a large coverage (up to 100 m) and it measures time accurately up to 0.001 second.[31] It could be used for training in vivo indoor and outdoor, which is not yet possible with virtual reality solution.[16] Accordingly, the B-percept system aims to simulate the real shotgun sports technique in vivo by giving detailed and immediate feedback about reaction time results and shooting accuracy which could positively enhance performance expectancy and self-efficacy. The B-percept system is designed for research about training and assessing reaction time and performance expectations in shotgun sports.

2 | MATERIALS AND METHODS

2.1 | Participants

Thirteen males and six females specialist participants (experience ±2.8 years) of military pentathlon (aged 24 ± 2.6 years., height 1.71 ± 0.13 m, weight 67.4 ± 4.2 kg) were recruited from a population of 118 students of a high sport-school of military and were given informed consent to participate in the study for 8 weeks, and to be photographed for research purposes. Participants had regular sports activities, an average of 12 hours a week. They had no physical, hearing, or visual impairments. This study was approved by the Institutional Review Boards of both University of Bordeaux and the ECOTIDI Laboratory-UR16ES10 of the Virtual University of Tunisia following the declaration of Helsinki for human experimentation.[32]

2.2 | Apparatus and experimental setup

B-precept RF transceiver Module was mounted (Figure 1) on a Beechwood shotgun[33] in order to have a comparable training gun dimension (850 mm), weight (4.8 kg) and form with a 10-m air Riffel. The Beechwood shotgun was remotely connected to a laptop using the following specifications: Windows 10 Edition Professional (X64), Intel Core i5 at 2.40 GHz, 12 Go DDR4, Samsung SSD 850 EVO 500 GB SATA III with a preinstalled version of B-percept software v.1.7. Accordingly, the reaction time is calculated (Equation (1)) when the participant presses the trigger button to stop the LED signal. Thus, a "*Stop timer TMR0*" command is activated as illustrated (Figure 2B) in the program code of B-percept microcontroller.

$$T_t = (T_{sig}\ n) + (T_{lat}\ \ (n-1)) + \sum_{i=0}^{+\infty} a_i.i, \tag{1}$$

where T_t is the test duration, T_{sig} the signal time, n the number of trials, T_{lat} the latency time, a_i the value of error intervals [0, 100 milliseconds], and i the number of errors.

2.2.1 | Use of the high-speed digital camera

Two high-speed cameras (Sony FDR-AXP33, Sony; Tokyo, Japan; 4K-HD 1080, shutter speed 1/10 000 of second) were associated to record flashing LEDs (ie, B-percept LED and Shotgun LED) during testing process of one at 240 frames per second (fps). Videos were synchronized (eg, Time Code TC-Link) and edited by a professional video editor (eg, Magix video pro x5 Multicam-editing software http://www.magix.com) then de-interlaced to 480 fps (eg, VirtualDub-1.10.4 for Windows).[34] Accordingly, videos were analyzed frame-by-frame to find the frame at which the LED light as stimuli start to change (Figure 2A—frame1) and the frame at which the Shotgun's LED light starts to change (Figure 2A—frame 20). The time interval calculated between video frames illustrates the reaction time of participants and it was used to assess a randomized control of the calibration and reliability of B-percept system time-base counter measurements (Equation (2)).

$$\begin{aligned} t &= (F_{P2} - F_{P1}) - 1_{fps} \\ RT &= t(\frac{1}{480_{fps}}(2\sqrt{n_{fps}}) \end{aligned} \tag{2}$$

2.3 | The procedure of the experiment

The training and testing process of the shotgun were carried in a zero LUX Cimmerian room[34] (ref: Luxmeter, Voltcraft MS-1300) in an average temperature of 24° (March-April 2019).[35,36] To standardize the physical conditioning factor participants had received training sessions for 3 hours/week during 6 weeks (1.30 hours/day; 2 days/week) from 4 PM to 5:30 PM.[37] Trainings were: moderate-intensity running, fitness and short circuits of parkour, and 3 × 100 shoots using a B-percept shotgun simulator. Moreover, participants have received exhaustive information about the testing protocol and they were familiarized with the handling of the shotgun simulator. Consequently, experiments were organized as follows:

1. At the beginning of the B-percept test, participants have to predict the score they think can realize within 100 repetitions (Figure 3B). At the end of the test, they do the same and predict the number of successful attempts they think had passed. Indeed, the protocol stipulates that the tested subject should not be informed about the real score calculated by the B-percept. Finally, the predicted score is automatically saved with his corresponding reaction time results form. No instructions were given during practicing.

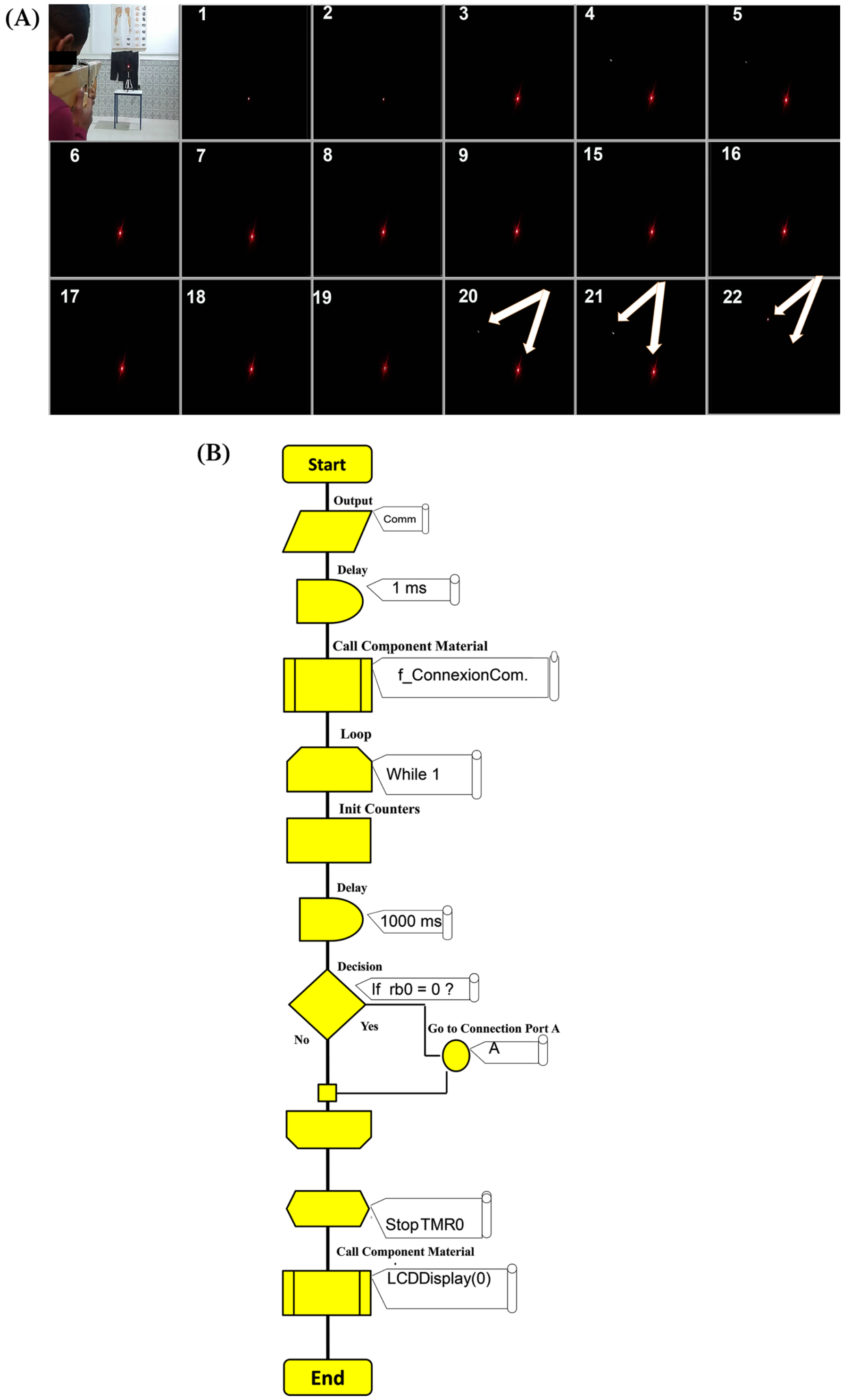


FIGURE 2 (A) Illustration of time interval between video frames showing B-percept LED lighting signals (frame 1) and Shotgun LED start (frame 20) matching the reaction time of the participant. (B) Source code of B-percept timer for 1000 milliseconds

2. Using the B-percept simulator, participants should be standing in a rifle-shooting position in front of a simple visual stimulus. Participants should react as fast as possible to stop the red-colored LED light placed at 5 m. This distance was adopted according to the standards of optimal monocular visibility Monoyer scale.[38]
3. A sound signal (80 db) announces the beginning of the testing process, after which, there is a flashing LED light signal repeating until registering 100 successful reaction time results. Correspondingly, the signal length is 1000 milliseconds and the latency within signals is 5000 milliseconds.
4. Prediction results are calculated based on the first 100 trials of each participant.

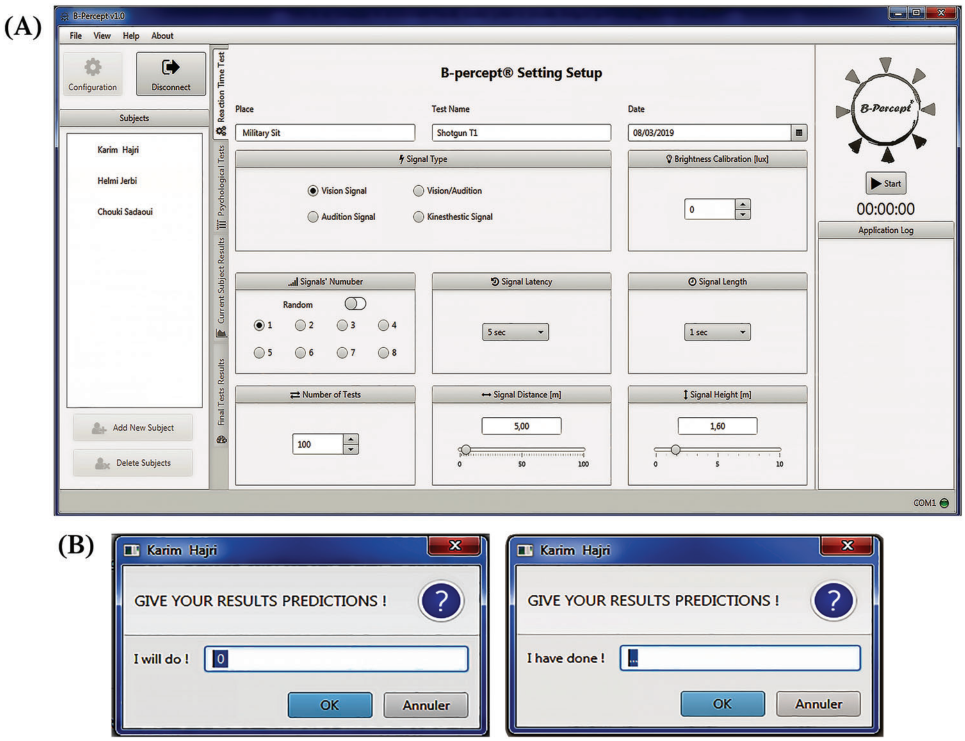


FIGURE 3 (A) Screenshot of B-percept setting setup of simple reaction time test for one LED light signal. (B) Screenshot of B-percept score prediction before tests

5. To assess the effect of technics' transfer of learning,[12] every participant was asked, at the beginning of the experiments and at the end, to accomplish 10 Clay pigeon targets shots in a training area. Indeed the number of Clay pigeons used for testing was reduced, to less than 25-target competition,[39] for two reasons: first, to reduce Clay targets waste. Second, because we need to invest the unused Clay's fund to develop a new electronic wireless Clay prototype to be used with the B-percept system in real training area. The prototype will be reusable for sports training.
6. To reduce evaluative social concerns, participants were tested one by one and asked about their predictions privately and they were informed that results will be confidentially coded by the research staff[40] with no personal identification.

2.4 | Statistical analysis

This research aims to find a strategy to improve the reaction time in shotgun sports by using a wireless electronic simulation protocol. Data are reported as mean ± SD and confidence intervals at the 95% level (95% CI). The effect size (d) was calculated using GPOWER software (Bonn FRG, Bonn University, Department of Psychology). The following scale was used to interpret d: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; and >2.0, very large. The normality of the distribution was acceptable for all variables. Therefore, the paired independent sample t test was applied to compare differences within essays and between subjects. Moreover, the variables' association was assessed using Pearson correlation coefficients. The coefficient of determination (R^2) was calculated to identify the level of common variance between B-percept measured time and video recorded time by frame. We used Bonferroni correction for multiple comparison adjustments. We assessed absolute and relative reliability using the SE of mean (SEM), intraclass correlation coefficient (ICC). The proportions of the distance variance between scores of predictions were assessed using the delta variation as shown in Equation (3). Indeed, calculations and statistical analyses were performed using MedCalc v.14.8.1.0 (Ostend, Belgium), Microsoft Excel 14 for Windows, and SPSS 21.0 (SPSS, Inc. Chicago, IL, USA).

$$\Delta_p = \frac{Sg2_{\%} - Sg1_{\%}}{Sg1_{\%}} x100 \tag{3}$$

where Δp is the delta variation of predictions, $Sg1_{\%}$ the value before the tests, and $Sg2_{\%}$ the value after the test.

3 | RESULTS

3.1 | Reaction time results in simulated shotgun

Table 1 presents the comparison between the B-percept system and the video totalize method[41] measurement results of 100 succeeding reaction times of one participant randomly selected. Accordingly, the analysis of variance (ANOVA) by pairwise comparison of means and SD showed no significant difference ($P < .001$) between measurement methods. The ICC value and the Cohen's *d* value for simple size measurement showed, also, a high reliability of results.

Table 2 presents a comparison between T1 and T2 for B-percept measurement systems. Thus, the paired sample *t* test shows that pretest and posttest results are significantly different at $P = .0002$. Moreover, the test of within-subject effects (ie, Greenhouse-Geisser) confirms a global assumed Sphericity at $P < .001$. ICC indicates an average reliability of 61.3% among measurements in T1 and T2. Conversely, the coefficient of determination (R^2) is limited to 20.50%, which could limit the possibility of predicting T2 results from T1 ones. This low R^2 could be caused by the variance within repetitions: 1-10; 21-30; 61-70, and 81-90 (Figure 4).

TABLE 1 Validation results of measurement reliability

Method	N	Mean	SEM diff. (95%)	C. var. (%)	ICC	*d*
B-percept	100	0.356 ± 0.15	0.000053 0.0006 to 0.0008	0.0365	1000 0.9996 to 1.00	0.0006
V-totalize	100	0.356 ± 0.15				

TABLE 2 Comparison of 100 repeated reaction time classified by 10 attempts

Factors		Mean ± SD	*t*	SEM diff. (95%)	*P*	*d*
1–10	-T1	0.364 ± 0.03	4401	0.0083 (−0.054/−0.019)	0.000	1.74
	-T2	0.327 ± 0.02				
11-20	-T1	0.359 ± 0.03	1298	0.0113 (−0.033/0.010)	0.211	0.56
	-T2	0.347 ± 0.00				
21–30	-T1	0.381 ± 0.03	3172	0.016 (−0.055/−0.011)	0.005	1.13
	-T2	0.347 ± 0.03				
31-40	-T1	0.362 ± 0.05	1513	0.0121 (−0.039/0.008)	0.148	0.36
	-T2	0.347 ± 0.03				
41-50	-T1	0.357 ± 0.06	1894	0.0134 (−0.044/0.017)	0.074	0.27
	-T2	0.344 ± 0.03				
51-60	-T1	0.371 ± 0.04	1544	0.0079 (−0.028/0.004)	0.140	0.30
	-T2	0.359 ± 0.04				
61–70	-T1	0.367 ± 0.02	3226	0.0087 (−0.046/−0.009)	0.005	1.09
	-T2	0.339 ± 0.03				
71-80	-T1	0.336 ± 0.04	0.345	0.0114 (−0.027/0.020)	0.734	0.08
	-T2	0.333 ± 0.04				
81–90	-T1	0.362 ± 0.03	2131	0.0121 (−0.053/−0.0003)	0.032	0.86
	-T2	0.336 ± 0.04				
91-100	-T1	0.359 ± 0.04	1890	0.0119 (−0.05/0.002)	0.075	0.63
	-T2	0.335 ± 0.35				

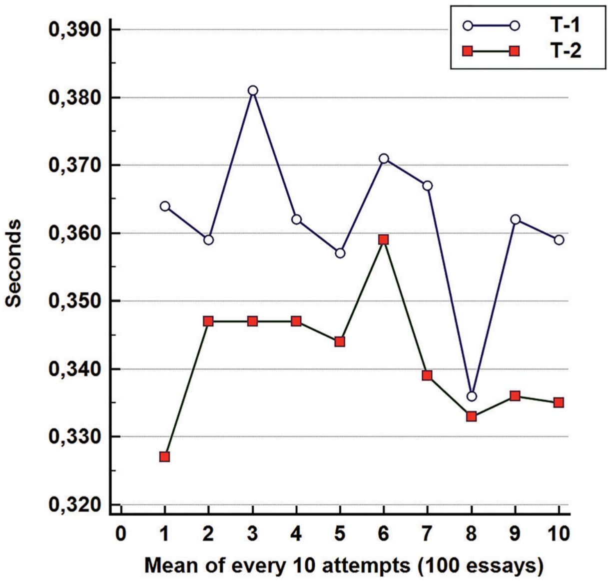


FIGURE 4 Comparison of participants' mean reaction time in tests and retest of every 10 attempts during B-percept simulator test[42]

TABLE 3 Comparison of clay pigeon shotgun results

Factors	n	Mean ± SD	*t*	SEM diff. (95%)	*P*	R^2	*d*
T1	19	6.10 ± 1.32	4698	0.3361 (0.872-2285)	0.0002	0.186	0.015
T2		7.68 ± 1.41					

3.2 | Clay pigeon shooting results

The results of Clay pigeon shotgun pretest (T1) and post-test (T2) presented in Table 3 show a significant progression of performance at $p = .0002$. Thus, the small value of the coefficient of determination (R^2) indicates that the model explains a small part of the variability between tests. Moreover, it implies that the performance improvement in T2 could not be predictable by T1 results.

3.3 | Score predictions

Table 4 shows a statistical summary from the comparison of predictions before and after tests with shotgun simulator scores for 100 attempts. Thus, the results before T1 are significantly different from post-test ones as well as real results ones at $P < .05$. However, they are not significantly different from T2 pretest predictions.

The T2 results show that there is no difference between pretest predictions because there is no significant difference, neither from those made before T1 nor after T2. The coefficient of determination (R^2) indicates that T1 pretest result could predict only 22.72% from after test results and 17.01% real score that participants could have. However, results before T2 could predict 32.23% from post-test ones and only 22.40% of T2 real score results (Figure 5).

4 | DISCUSSION

The present study was designed to determine the effect of an electronic simulation system designed for research about training and assessing reaction time and performance expectations in Shotgun sport. The most obvious finding to emerge from this study is that measurement's consistency of the B-percept system has provided high accuracy and reliability, which was revealed through a comparison to the video-totalize method. Moreover, it was demonstrated that using AT "Transparent" mode for data transmission (ie, Xbee point-to-point connection) as recommended by Faludi,[43] Mayalarp, Limpaswadpaisarn[44] during experiments and training process, was unfailing to interference or signal loss, despite the

TABLE 4 Score predictions before and after B-percept testing process *vs* real scores

Factors		Mean diff. ± SD	95% CI	*P*
T1-PRD1	-T1-PRD2	10.26 ± 3.00	0.12 to 20.41	0.05
	-T1-RSC	36.21 ± 3.12	25.66 to 46.76	0.0001
	-T2-PRD1	5.79 ± 2515	−2.71 to 14.22	0.50
	-T2-PRD2	17.32 ± 3.03	7.07 to 27.55	0.00
	-T2-RSC	24.89 ± 2.69	15.78 to 34.01	0.0001
T1-PRD2	-T1-PRD1	−10.26 ± 3.00	−20.41 to −0.12	0.05
	-T1-RSC	25.95 ± 3.11	15.44 to 36.46	0.0001
	-T2-PRD1	−4.47 ± 2.65	−13.41 to 4.47	1.00
	-T2-PRD2	7.05 ± 2.91	−2.79 to 16.89	0.39
	-T2-RSC	14.63 ± 3.18	3.88 to 25.38	0.00
T1-RSC	-T1-PRD1	−36.21 ± 3.12	−46.76 to −25.66	0.0001
	-T1-PRD2	−25.95 ± 3.11	−36.46 to −15.44	0.0001
	-T2-PRD1	−30.42 ± 1.68	−36.09 to −24.75	0.0001
	-T2-PRD2	−18.89 ± 2.05	−25.81 to −11.98	0.0001
	-T2-RSC	−11.32 ± 2.22	−18.81 to −3.82	0.00

distance of 30 m among the participant and the remote computer. The second findings are linked to the choice of 5 seconds latency within LED signals which was practical to reduce uncertainty impact due to accidental or recurrent anticipating reactions. This is also in good concordance with earlier observations of Teichert, Ferrera,[45] which showed that subjects increase accuracy by prolonging the decision process.

The comparison of the B-percept shotgun results showed that the percentage of R^2 explains only 20.50% of predicted training-related gains in reaction time. Thus, the difference between pretest and posttest suggests reflecting on the effect of the programed physical activity exercises on shooting position stability and adaptations to the experimental conditions (ie, the Beechwood Shotgun, the darkroom, and the visual signal solicitation). Thus, these findings are in line with Larue, Bard,[46] and Kayihan, Ersöz[47] research who highlighted the effects of physical training preparations on fundamental factors, such as stability, on the shooting technique position.[24] Furthermore, results could also highlight the impact of shotgun simulation trainings for the period of 8 weeks on the effectiveness of signals perception. It is encouraging to compare these outcomes with Causer, Bennett[13] ones, who had analyzed the sub-disciplines of shotgun and had found a significant correlation $P < .05$ between the practice and the gaze behavior and kinematic assessment between sub-elite shooters at successful and unsuccessful shots. However, he noted that for elite shooters differences in physical and physiological characteristics appear less likely to discriminate, while the importance of other components, such as the ability to anticipate and to make decisions, is magnified. The nature of sport means high levels of uncertainty, requiring athletes to anticipate action requirements before selecting the most appropriate response from a range of possibilities.[48] Thus, experienced shooters demonstrate a more efficient gun barrel motion, as characterized by a smaller gun barrel displacement and a more efficient timing strategy, which indicates the positive effect of practice in shooting sport.[48]

Despite the small number of used Clay pigeons during experiments, results showed a significant increase in successful shoots in T2 results ($P < .0002$). Definitely, the enhancement of performance, due to the transfer of learning technics, could have several possible explanations: first, it is possible that technical adaptations of the participant's to the shooting position could have a positive influence on results. Moreover, it may also be the result of a cognitive adaptation such as the improvement of attention solicitations in gazing targets,[8,13,49] space searching behavioral technics,[14,50] and the improvement of reaction time to visual signals stimuli. Nevertheless, it is unwise, given the low coefficient of determination, to assert predicting the results of clay shotgun through those the simulation test.

The score prediction test was integrated to assess the participants' sensitivity to their level of performance as well as the level of difficulty felt after practicing the simulation test. Thus, the use of this test was argued in psychology literature where the term "prediction" tends to be used to describe the capacity for cognitive processing in working[51] and playing.[52] This finding corroborates the ideas of Mitchell, Hopper[53] who stated that ability estimates (which are a major

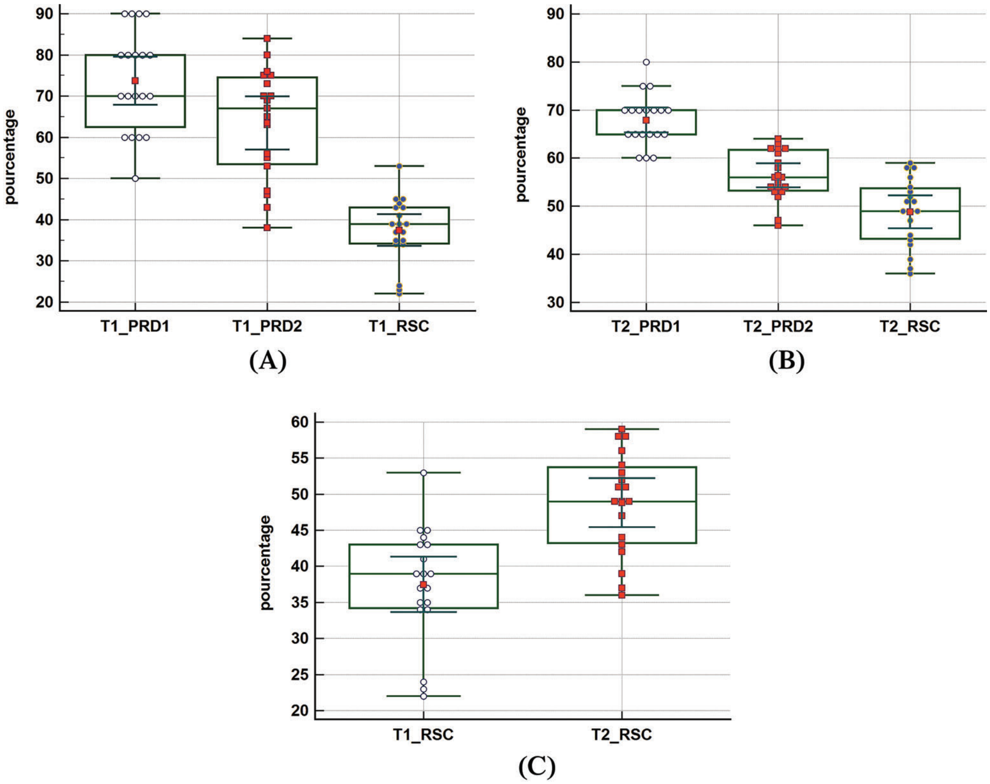


FIGURE 5 (A) Predictions in T1 vs real score of participants. (B) Predictions in T2 vs real score. (C) Comparison of real percentage of successful shots in B-percept using

part of self-efficacy) may be the best predictors initially of performance on a complex task, but they become less important in comparison with expectations and goals once the skills are well learned.[51,54] Indeed, it is encouraging to compare this figure with the first part of findings of the present research, where the difference between practitioners' post-test predictions in T1-T2 and their real results was significant at $P < .0001$. However, what is surprising is that in spite of the numerous training repetitions through the experimentation process, participants were just able to predict 32.23% of successful results.

5 | CONCLUSIONS

In this paper, it was undertaken to design an electronic simulator for indoor and outdoor training as well as for scientific evaluation of beginners in shotgun sport. Thus, the most obvious finding to emerge from using the B-percept simulator is the significant enhancement of participants' reaction time to visual stimuli. Additionally, although experimentation of the electronic communication system was technically reliable and safe, this helped participants to perform 15 000 electronic simulator shots in 8 weeks of practice. Consequently, there was a decrease in the number of used Clay pigeons (ie, we only used 380 units, which means that almost 1575 kg of molded petroleum pitch waste was avoided) as it harms animals' lives and ecosystems.[55] Furthermore, using electronic shotgun simulator helps shotgun sport to be less expensive especially for beginners, while preserving the needed motivation associated to the hunting activity. Thus, the empirical findings in this study provided new ways to better understand the shooter behavior and to lay out original ideas and new scientific research axes about military and security-agent trainings. Basically, the findings give important conclusions about the future developments to be undertaken to perform accurate measurements of reaction time using the B-percept simulator. Thus, future works should involve the participant's dynamic-body observation in outdoor conditions. Conversely, in this paper, the study was a first step of a global project we are working on. Thus, the experiments were limited by the small number of participants as well as the small budget used to buy Clay pigeons. Moreover, the testing process should now be organized in real conditions of training (eg, with more than 75 to 100 clay shootings per participant). Further development should be about adding LED light signals and Global Positioning System GPS-based tracking system on clays for helping its geo-localization on wetlands and dry land areas.

ACKNOWLEDGEMENT

The authors are thankful to the coaches and volunteer participants for taking part in the experiments.

PEER REVIEW INFORMATION

Engineering Reports thanks Shamsi S. Monfared and other anonymous reviewer(s) for their contribution to the peer review of this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Boubaker Ben Ali: Conceptualization; data curation; formal analysis; funding acquisition; methodology; validation. **Chawki Fraj:** Data curation; investigation; visualization; writing-original draft. **Olfa Oueslati:** Visualization; writing-review and editing. **Eric Dugas:** Methodology; supervision.

ORCID

Boubaker Ben Ali https://orcid.org/0000-0003-1783-3386

REFERENCES

1. Bracq MS, Michinov E, Arnaldi B, et al. Learning procedural skills with a virtual reality simulator: an acceptability study. *Nurse Educ Today*. 2019;79:153-160. https://doi.org/10.1016/j.nedt.2019.05.026.
2. Harvey C, Selmanović E, O'Connor J, Chahin M. A comparison between expert and beginner learning for motor skill development in a virtual reality serious game. *Vis Comput*. 2019;1:1-15. https://doi.org/10.1007/s00371-019-01702-w.
3. Wang Y, Wan B, Li H, Shan G. A wireless sensor system for a biofeedback training of hammer throwers. *Springerplus*. 2016;5:1395. https://doi.org/10.1186/s40064-016-3069-5.
4. Li N, Huang J, Feng Y. Human performance modeling and its uncertainty factors affecting decision making: a survery. *Soft Comput*. 2020;24:2851-2871. https://doi.org/10.1007/s00500-019-04659-z.
5. Ducrocq E, Wilson M, Vine S, Derakshan N. Training attentional control improves cognitive and motor task performance. *J Sport Exerc Psychol*. 2016;38:521-533. https://doi.org/10.1123/jsep.2016-0052.
6. Lebiere CJ, Stocco A, Reitter D, Juvina I. Scaling up high-fidelity cognitive modeling to real-world applications; 2010.
7. Lyu X, Li Z. Correlations between human performance in information seeking, information integration, and overall process in diagnostic tasks. *Int J Human Comput Interact*. 2020;36:285-294. https://doi.org/10.1080/10447318.2019.1631545.
8. Azouvi P, Samuel C, Louis-Dreyfus A, et al. Sensitivity of clinical and behavioural tests of spatial neglect after right hemisphere stroke. *J Neurol Neurosurg Psychiatry*. 2002;73:160-166. https://doi.org/10.1136/jnnp.73.2.160.
9. Chengen W, Zhuming B, Li Da X. IoT and cloud computing in automation of assembly modeling systems. *IEEE Trans Indus Informat*. 2014;10:1426-1434. https://doi.org/10.1109/tii.2014.2300346.
10. Li S, Da Xu L, Wang X. Compressed sensing signal and data acquisition in wireless sensor networks and internet of things. *IEEE Trans Indus Informat*. 2012;9:2177-2186. https://doi.org/10.1109/TII.2012.2189222.
11. Müller-Hansen F, Schlüter M, Mäs M, et al. Towards representing human behavior and decision making in earth system models–an overview of techniques and approaches. *Earth Syst Dynam*. 2017;8:977-1007. https://doi.org/10.5194/esd-8-977-2017.
12. Anderson JR, Betts S, Bothell D, Hope R, Lebiere C. Learning rapid and precise skills. *Psychol Rev*. 2019;126:727-760. https://doi.org/10.1037/rev0000152.
13. Causer J, Bennett SJ, Holmes PS, Janelle CM, Williams AM. Quiet eye duration and gun motion in elite shotgun shooting. *Med Sci Sports Exerc*. 2010;42:1599-1608. https://doi.org/10.1249/MSS.0b013e3181d1b059.
14. Brown AA. Modeling and simulating the dynamics of the 'death star' shotgun target. *Sports Eng*. 2017;20:17-27. https://doi.org/10.1007/s12283-016-0214-x.
15. Baca A, Kornfeind P. Stability analysis of motion patterns in biathlon shooting. *Hum Mov Sci*. 2012;31:295-302. https://doi.org/10.1016/j.humov.2010.05.008.
16. Harvey C, Selmanovic E, O'Connor J, Chahin M. Validity of virtual reality training for motor skill development in a serious game. Paper presented at: 2018 10th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games); 2018: IEEE. doi:10.1109/VS-Games.2018.8493447.
17. Davidson R, Thomson RD, Birkbeck AE. Computational modelling of the shot pattern of a sporting shotgun. *Sports Eng*. 2002;5:33-42. https://doi.org/10.1046/j.1460-2687.2002.00089.x.

18. Perroy RL, Belby CS, Mertens CJ. Mapping and modeling three dimensional lead contamination in the wetland sediments of a former trap-shooting range. *Sci Total Environ*. 2014;487:72-81. https://doi.org/10.1016/j.scitotenv.2014.03.102.
19. Monfared SS, Tenenbaum G, Folstein JR. Anticipation in sharp shooting: cognitive structures in detecting performance errors. *Psychol Sport Exerc*. 2019;45:101555. https://doi.org/10.1016/j.psychsport.2019.101555.
20. Mohamed MN, Azhar AH. Postural sway and shooting accuracy of skilled recurve archers. *Move Health Exerc*. 2012;1:49-60. https://doi.org/10.15282/mohe.v1i0.5.
21. Fenici R, Ruggieri M, Brisinda D, Fenici P. Cardiovascular adaptation during action pistol shooting. *J Sports Med Phys Fitness*. 1999;39:259.
22. Dadswell C, Payton C, Holmes P, Burden A. The effect of time constraints and running phases on combined event pistol shooting performance. *J Sports Sci*. 2016;34:1044-1050. https://doi.org/10.1080/02640414.2015.1088163.
23. Mohamed MN, Norman WMNW, Linoby A, Sariman MH, Azam MZM. Breathing pattern influence to the shooting performance. In: Proceedings of the International Colloquium on Sports Science, Exercise, Engineering and Technology (ICoSSEET 2014); Singapore: Springer Singapore; 2014. doi:10.1007/978-981-287-107-7_34.
24. Mononen K, Konttinen N, Viitasalo J, Era P. Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. *Scand J Med Sci Sports*. 2007;17:180-185. https://doi.org/10.1111/j.1600-0838.2006.00549.x.
25. Insabato A, Dempere-Marco L, Pannunzi M, Deco G, Romo R. The influence of spatiotemporal structure of noisy stimuli in decision making. *PLoS Comput Biol*. 2014;10:e1003492. https://doi.org/10.1371/journal.pcbi.1003492.
26. Nitzsche K. Entwicklung eines Messplatzes zur Objektivierung der Biathlonschießleistung. *Leipziger Sportwissenschaftliche Beiträge*. 2000;41:58-89.
27. Asadipour A, Debattista K, Chalmers A. A game-based training approach to enhance human hand motor learning and control abilities. Paper presented at: 2015 7th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games); 2015: IEEE. doi:10.1109/VS-GAMES.2015.7295759.
28. Wolfe AA, Peak K, Burch J, Burch G. The effects of innovative shotgun shooting methods on collegiate shotgun shooters. *Int J Phys Ed Fit Sports*. 2018;7:57-65. https://doi.org/10.26524/ijpefs1836.
29. Ben Ali B, Ladhari S, Echaieb N. B-percept: Dispositif pour mesurer le temps de réaction et la prise de décision simple et complexe aux stimuli visuels; 2017:24747. https://patents.google.com/patent/TN2015000488A1/.
30. Nagaraja A, Mangathayaru N, Rajashekar N, Kumar TS. A survey on routing techniques for transmission of packets in networks. In: Engineering & MIS (ICEMIS), International IEEE Conference on: IEEE; 2016. doi:10.1109/ICEMIS.2016.7745349.
31. Ben Ali B, Dugas E, Naceur A, Romdhani I. A new Zigbee-based device for measuring visual reaction time in sport activities. *IEEE*. 2017;1:1-6. https://doi.org/10.1109/ICEMIS.2017.8273005.
32. World Medical Association. World Medical association declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013;310:2191.
33. Gérard J, Guibal D, Cerre J-C, Paradis S. *Atlas des bois tropicaux: Caractéristiques technologiques et utilisations*. Paris: Editions Quae; 2016. https://books.google.tn/books?id=nmaSDQAAQBAJ&hl=fr&source=gbs_navlinks_s.
34. Tsui CM, Yan YK, Chan HM. Calibration of stopwatches by utilizing high speed video recordings and a synchronous counter. *NCSLI Meas*. 2016;6:64-71. https://doi.org/10.1080/19315775.2011.11721566.
35. Bérubé L. Institut Philippe Pinel de M. *Terminologie de neuropsychologie et de neurologie du comportement*. Montréal: Cheneliére; 1991.
36. Ruger M, Gordijn MC, Beersma DG, de Vries B, Daan S. Time-of-day-dependent effects of bright light exposure on human psychophysiology: comparison of daytime and nighttime exposure. *Am J Physiol Regul Integr Comp Physiol*. 2006;290:R1413-R1420. https://doi.org/10.1152/ajpregu.00121.2005.
37. Ball KA, Best RJ, Wrigley TV. Body sway, aim point fluctuation and performance in rifle shooters: inter- and intra-individual analysis. *J Sports Sci*. 2003;21:559-566. https://doi.org/10.1080/0264041031000101881.
38. Ruiz F, Goldberg M, Lemonnier S, et al. High quality standards for a large-scale prospective population-based observational cohort: Constances. *BMC Public Health*. 2016;16:877. https://doi.org/10.1186/s12889-016-3439-5.
39. Federation ISS. *ISSF News: Official Publication of ISSF, International Shooting Sport Federation*. Shotgun Rules ISSF Munich, Germany: ISSF Administrative Council; 2020.
40. Weinberg RS, Yukelson D, Jackson A. Effect of public and private efficacy expectations on competitive performance. *J Sport Psychol*. 1980;2:340-349. https://doi.org/10.1123/jsp.2.4.340.
41. Graham RM. Stopwatch calibrations, part II: the totalize method. *NCSLI Meas*. 2006;1:72-73.
42. Ben Ali B, Taktak H, Fraj C, Oueslati O, Dugas E. A Zigbee-based system for simulating, training and measuring visual reaction time in shotgun sport. Paper presented at: 2019 International Conference in Engineering Applications (ICEA); 2019:1-6. doi:10.1109/ceap.2019.8883474.
43. Faludi R. *Building wireless sensor networks: with ZigBee, XBee, arduino, and processing*. Gravenstein Highway North. Sepbastopol: O'Reilly Media, Inc.; 2010. doi:/book/10.5555/1965443.
44. Mayalarp V, Limpaswadpaisarn N, Poombansao T, Kittipiyakul S. Wireless mesh networking with XBee. Paper presented at: 2nd ECTI-Conference on Application Research and Development (ECTI-CARD 2010); 2010; Pattaya, Chonburi, Thailand.
45. Teichert T, Ferrera VP, Grinband J. Humans optimize decision-making by delaying decision onset. *PLoS One*. 2014;9:e89638. https://doi.org/10.1371/journal.pone.0089638.
46. Larue J, Bard C, Otis L, Fleury M. Stability in shooting: the effect of expertise in the biathlon and in rifle shooting. *Can J Sport Sci*. 1989;14:38-45.

47. Kayihan G, Ersöz G, Özkan A, Koz M. Relationship between efficiency of pistol shooting and selected physical-physiological parameters of police. *Policing*. 2013;36:819-832. https://doi.org/10.1108/pijpsm-03-2013-0034.
48. Causer J, Williams AM. Improving anticipation and decision making in sport. In: Routledge handbook of sports performance analysis. New York, NY: Routledge/Taylor & Francis Group; 2013;21-31.
49. Wilkie RM, Wann JP, Allison RS. Modeling locomotor control: the advantages of mobile gaze. *ACM Trans Appl Percept*. 2011;8:1-18. https://doi.org/10.1145/1870076.1870077.
50. Brooks J, Seeanner J, Hennessy S, et al. Interactive tools for measuring visual scanning performance and reaction time. *Am J Occup Ther*. 2017;71:1-6. https://doi.org/10.5014/ajot.2017.020461.
51. Hughes G, Desantis A, Waszak F. Mechanisms of intentional binding and sensory attenuation: the role of temporal prediction, temporal control, identity prediction, and motor prediction. *Psychol Bull*. 2013;139:133-151. https://doi.org/10.1037/a0028566.
52. Harvanko AM, Schreiber LR, Grant JE. Prediction of alcohol and gambling problems in young adults by using a measure of decision making. *J Addict Med*. 2013;7:314-319. https://doi.org/10.1097/ADM.0b013e31829a2f32.
53. Mitchell TR, Hopper H, Daniels D, George-Falvy J, et al. Predicting self-efficacy and performance during skill acquisition. *J Appl Psychol*. 1994;79:506-517. https://doi.org/10.1037/0021-9010.79.4.506.
54. Pentland A, Liu A. Modeling and prediction of human behavior. *Neural Comput*. 1999;11:229-242. https://doi.org/10.1162/089976699300016890.
55. Wilson MR. Anxiety: attention, the brain, the body and performance. *The Oxford Handbook of Sport and Performance Psychology*. New York: Routledge; 2012:173-190. https://doi.org/10.1093/oxfordhb/9780199731763.013.0009.

How to cite this article: Ben Ali B, Fraj C, Oueslati O, Dugas É. Environmental impact and performance assessment of a new Zigbee-based shotgun training system. *Engineering Reports*. 2020;2:e12309. https://doi.org/10.1002/eng2.12309