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# Always doing your best? Effort and performance in dynamic settings \*

Nicolas Houy<sup>†</sup> Jean-Philippe Nicolai<sup>‡</sup> Marie Claire Villeval<sup>§</sup>

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## Abstract

Achieving an ambitious goal frequently requires succeeding in a sequence of intermediate tasks, some being critical for the final outcome, and others not. However, individuals are not always able to provide a level of effort sufficient to guarantee success in all such intermediate tasks. The ability to manage effort throughout the sequence of tasks is therefore critical when resources are limited. In this paper we propose a criterion of importance that is person- and context-specific, as it is based on how an individual should optimally allocate a limited stock of exhaustible efforts over tasks. We test this importance criterion in a laboratory experiment that reproduces the main features of a tennis match. We show that our importance criterion is able to predict the individuals' performance and it outperforms the Morris importance criterion that defines the importance of a point in terms of its impact on the probability of achieving the final outcome.

*JEL Classification:* C72, C92, D81.

*Keywords:* Effort, critical ability, Morris-importance, choking under pressure, experiment

## 1 Introduction

Consider a politician who is a candidate to an important election. Her final and only goal is to be elected. However, this final outcome will depend on the aggregation of the results obtained at many intermediary steps. The candidate will need to convince voters in a small town

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<sup>†</sup>Univ Lyon, CNRS, GATE, UMR5824, 93 Chemin des Mouilles, F-69130, Ecully, France. houy@gate.cnrs.fr

<sup>‡</sup>EconomiX-CNRS, University of Paris Nanterre and ETH Zürich, Chair of Integrative Risk Management and Economics. nicolai.jeanphilippe@parisnanterre.fr

<sup>§</sup>Univ Lyon, CNRS, GATE, UMR5824, 93 Chemin des Mouilles, F-69130, Ecully, France; IZA, Bonn, Germany. villeval@gate.cnrs.fr

meeting but also donors in an important fundraising reception and possibly millions of voters in the final debate broadcast on national TV. The situation described above where the final goal depends on a sequence of various tasks covers most professional lives - *e.g.*, obtaining a tenured academic appointment depends on the quality of publications but also on presentations in seminars, reviewing articles, supervising students-, and also sport competitions -*e.g.*, tennis games where the final result depends on completion of single points or penalty kicks sessions in soccer games.

Intuitively, we can agree that all these intermediary steps do not have the same importance: a national debate certainly is more directly impactful on the probability of success of a candidate, while raising funds is certainly necessary. Yet, beyond intuition, we require a formal and precise definition of "importance" of an intermediate step for an individual. The first quantitative criterion of importance has been proposed by Morris (1977) and we will call it the "Morris-importance criterion". It measures the importance of a given step for an individual as the difference between reaching the final goal conditionally on having a success at the current task and reaching the final goal conditionally on having a failure at the current task. We have two ways to interpret this definition of importance. The first one is normative, considering this definition plainly as such, and hence hardly debatable: what should be called important is what has been defined as important. The second one is positive. It relies on an additional assumption: individuals perform differently – better or worse – at what they consider important tasks. This behavioral difference can be explained by higher levels of effort or, on the contrary, more stress when working at a task they deem more important, in a world where effort is an exhaustible resource (*e.g.*, Hancock and Desmond (2001); Hockey (2013)). If we adopt the positive view, we can propose alternative definitions of importance that can be ranked more or less relevant than the Morris-importance definition, as they predict more or less behavioral deviations in performance. In this perspective, we define importance with a criterion that differs from the Morris-importance criterion and we run a controlled laboratory experiment to test which criterion explains best the observed deviations in performance if such deviations can be observed.<sup>1</sup>

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<sup>1</sup>Note that as in Morris (1977), we define what importance is and measure how relevant our definition is to

Let us describe the model that allows us to derive our quantitative definition of importance, the HNV-importance criterion.<sup>2</sup> When considering an individual facing a sequence of tasks to perform, we model the situation in which the individual has a stock of exhaustible efforts to be used optimally, each effort used increasing the chance to succeed at each task.<sup>3</sup> While choosing the ideal moment to make an effort, the agent faces a trade-off between the immediate gain of being successful at a given task and the option value related to the possibility of using that effort later. This trade-off depends on the number of efforts left. The HNV-importance criterion defines importance as the value of making an effort at a given step when a given number of exhaustible efforts are left. Thus, like the Morris-importance criterion the HNV-importance criterion is not defined by the objective characteristics of a task, but it is person- and context-specific. In contrast to the Morris-importance criterion we add the notion of option value in the definition of importance; by taking a personal stock of effort into account, we focus on the incentives, or opportunity costs, an individual faces at each step. We first show that the Morris-importance and the HNV-importance criteria are significantly different in the sense that they may give very different predictions.

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explain behavior but we are not stating a theory to *explain* behavior. Let us illustrate this point by considering an individual that has to complete with success three intermediary steps in order to reach her final goal. A failure at any intermediary step means a global failure. Her "base" probability to succeed at any step is  $1/2$ . Using the Morris-importance criterion, the first intermediary step has a measure of importance of  $1/4$ . Indeed, if successful at the first step, the individual still has a  $1/4$  chance to succeed at the remaining two steps. If not successful at the first step, the individual has a 0 probability to have a global success by assumption. The importance is then  $1/4 \cdot 0 = 1/4$ . If successful and reaching the second intermediary step, the individual is now facing a step with importance  $1/2$ . Indeed, if successful at the second step, the individual still has a  $1/2$  chance to succeed at the remaining last step. If not successful at the second step, the individual has a 0 probability to have a global success. The importance is then  $1/2 \cdot 0 = 1/2$ . If we want the notion of importance to have any positive and relevant content, we need to assume that the individual's behavior will be modified and the *a priori* probability to succeed at the second step differs from the *a priori* probability to succeed at the first step because importance is no longer the same. But then, the computation we made for the probabilities to succeed at the global level in order to compute importance itself at each step is flawed: we should have taken into account the way behavior is modified by importance in subsequent steps in the very computation of importance. At best, we have a fixed-point problem, at worse a circular definition. The only way to escape this reasoning is to consider that the definition of importance is based on a model whose purpose is not to model the behavior of a more or less rational and forward-looking individual, but only to derive a definition whose relevance is to be tested empirically and to be used in predictive models. This methodological viewpoint is standard in the machine learning literature and has been defended by Friedman (1953) or Koopmans (1957) in economics.

<sup>2</sup>HNV stands for Houy-Nicolai-Villeval.

<sup>3</sup>Note that there is a literature in economics on the effects of goal-setting on performance (*e.g.*, Koch and Nafziger (2015); Goerg and Kube (2012); Clark et al. (2017)). In contrast, we are not interested in measuring the impact of goal-setting on performance but we examine how individuals allocate their effort depending on the succession of stages leading to a final outcome when the importance of these stages varies.

Our approach also differs from that of González-Díaz et al. (2012) who coined the concept of critical ability that focuses on the capacity of an agent to adapt his performance to the scale of the issue at stake. González-Díaz et al. (2012) insist in particular on individual heterogeneity in critical ability. Three interpretations of the concept are proposed by the authors. The critical ability may first be interpreted as the ability to deal with psychological pressure. Such interpretation appears close to the choking under pressure theory except that instead of being inefficient due to the pressure, the agent who possesses such a critical ability is not reactive to a stressful environment. A second interpretation considers critical ability as a special skill in allocating limited resources optimally across a set of actions. A third interpretation is the ability of an individual to understand when some situations are more crucial than others. González-Díaz et al. (2012) apply this concept to tennis players and use the Morris-importance criterion (Morris (1977)). They show that a player’s higher critical ability helps predict his overall career success and conclude that success depends on the ability to respond to pressure appropriately. However, they do not formally define critical ability, their paper assuming that critical ability means performing well when Morris-importance is high.<sup>4</sup>

Our second contribution is showing by means of a laboratory experiment designed for the purpose of importance criteria comparison, that the HNV-importance criterion can predict participants’ performance whereas the Morris-importance criterion fails. Our experiment uses a novel real effort task that involves using the mouse pointer to reach the center of a target appearing on the computer screen. Participants have to shoot as accurately as possible in the center of the target. The difficulty lies in the fact that a random perturbation is dynamically applied to the mouse position. The difficulty is *ex-ante* the same for each participant. Players

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<sup>4</sup>The idea of choking under pressure was first developed in psychology to demonstrate that the importance of an issue may generate pressure that will have negative effects on performance. In particular, Baumeister (1984) and Baumeister and Showers (1986) showed that pressure increases with the existence of competition between agents (see also, *e.g.*, Beilock and Carr (2001), DeCaro et al. (2011), Porcelli et al. (2012), Yu (2015)). Sanders and Walia (2012) insist on the fact that higher performance-contingent compensation may also have a negative impact on labor input if counterproductive processes decrease the marginal effectiveness of effort. Ariely et al. (2009) further showed in a series of field and lab experiments that very high monetary stakes tend to impair performance because they generate supra motivation and excess stress. Using tennis data, Cohen-Zada et al. (2017) found that males choke consistently under pressure and to a larger extent than females. Contradictory evidence has been shown in the analysis of penalty shootouts in football competitions (Apesteguia and Palacios-Huerta (2010), Kocher et al. (2012), Dohmen (2008)). Recent evidence has also shown that people may choke even under the pressure of non-monetary incentives (Kali et al. (2017)).

can play against a robot with a given ability (Robot treatment) but in order to test the impact of playing against a human being, we also let participants play against each other in some sessions (Human treatment).<sup>5</sup> We reproduce the same rules of point assignment as a tennis match. The point is won by the participant in the pair whose shot is closest to the target. The payoffs in the game depend on the final outcome of the competition. The first participant in the pair who wins at least four points with at least two points ahead of his opponent wins a round. The first participant who wins at least six rounds wins a set, and the first one who wins two sets wins the match. We complement our behavioral observations with electrophysiological measures, using skin-conductance responses to measure emotional arousal and evaluate stress throughout the experiment.

Our results show that the approach based on the Morris criterion of importance systematically fails to predict participants' shot performance. The approach based on the nature of the shot (*i.e.*, shots that determine whether the player will earn the round, the set, or the match *vs.* regular shots) has predictive value only for the round shot for the individual and the match shot for the opponent. In contrast, the HNV-importance for the optimal assignment of efforts predicts players' performance in the Human treatment when assuming that all players are endowed with the same stock of efforts, and in both treatments when allowing each player to differ in his stock of efforts. These results confirm that individuals react to incentives in this setting by taking into account the trade-offs arising from the comparison between the immediate gain of being successful at a task and the option value from using that effort later. Also, our physiological measures show no systematic evidence of choking under pressure or a negative effect of stress on the subjects' performance.

The remainder of this paper is structured as follows. Section 2 presents the modeling assumptions and the theoretical results. Section 3 details the experimental design and procedures. Section 4 presents the experimental results. Section 5 concludes.

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<sup>5</sup>Note that, as explained in footnote 1, we do not consider our model with the use of efforts as a model to be interpreted literally, but as a model giving predictions that we want to test. Hence, from that perspective we do not consider the difference between the decision making setting of a human playing against a robot and the game-theoretical setting of two humans playing against each other (see Klumpp et al. (2019) for instance). Solving the latter game is a different question than the one we tackle here and it should be addressed in another unrelated piece of work.

## 2 Model

### 2.1 Set-up

This paper considers various states and focuses on both the relationship between importance and states, and the relationship between importance and performance.

#### 2.1.1 States

Let  $S$  be a set of states. We add two absorbing states:  $\{W\}$  where the individual wins (or where the individual has definitely reached his goal) and  $\{L\}$  where he loses (or where the individual has definitely failed at reaching his goal). Let  $S^* = S \cup \{W\} \cup \{L\}$ . We denote by  $\Pi(S^*)$  the set of probability distributions over  $S^*$ . We define a transition probability between states  $p : S^* \times S^* \rightarrow [0; 1]$  such that  $\forall s \in S^*, p(s, \cdot) \in \Pi(S^*)$ , and  $p(\{W\}, \{W\}) = 1$  and  $p(\{L\}, \{L\}) = 1$ .

First, we define the probability that, starting from a given state, the individual reaches his final goal – state  $\{W\}$  – at some time.

**Definition 1.** (*Probability of reaching the final goal*) We call  $P : S^* \rightarrow [0, 1]$  the probability of reaching the final goal. This is usually referred to as the probability to hit state  $\{W\}$  and it is the minimal<sup>6</sup> non-negative solution to the following system:

$$\begin{cases} P(\{W\}) = 1 \\ \forall s \in S \cup \{L\}, P(s) = \sum_{s' \in S^*} p(s, s')P(s') \end{cases}$$

Let us provide an intuition for the linear system given in Definition 1. Let us assume an individual in state  $s \in S$ . He can reach states  $s_1, s_2, \dots$  with probabilities  $p_1 = p(s, s_1)$ ,  $p_2 = p(s, s_2), \dots$ , respectively. Conditionally on being in  $s_1$  (resp.  $s_2, \dots$ ), his probability of reaching the final goal is  $P(s_1)$  (resp.,  $P(s_2), \dots$ ). Then,  $P(s)$  is the sum of the conditional probabilities of reaching the final goal in latter states, weighted by the transition probability of reaching those states as next step.

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<sup>6</sup>If  $P$  is a minimal solution and  $P'$  is any solution, then  $\forall s \in S^*, P(s) \leq P'(s)$ . For more details, see Norris (1998). Notice that since  $P$  is the minimal non negative solution,  $P(\{L\}) = 0$ .

Let us define function  $s^+ : S \rightarrow S^*$  as the transition function when the individual is successful at a given state. An individual is said to be successful in state  $s \in S$  when he moves towards the next attainable state with the highest  $P$  value. Formally,<sup>7</sup>

$$\forall s \in S, s^+(s) = \arg \max_{s' \in S^*, p(s, s') > 0} P(s').$$

Similarly, we consider the function  $s^- : S \rightarrow S^*$  as the transition function when the individual is not successful at a given state.

$$\forall s \in S, s^-(s) = \arg \min_{s' \in S^*, p(s, s') > 0} P(s').$$

In order to define the importance of a given state, we use the probability function  $P$  and adapt the measure proposed by Morris (1977) for the tennis points case to our decision theory setting.<sup>8</sup>

**Definition 2. (*Morris-importance*)** *The measure of importance of a state  $s$  is given by the function  $I : S \rightarrow \mathbb{R}$ , defined as:  $\forall s \in S$ ,*

$$I(s) = P(s^+(s)) - P(s^-(s)). \tag{1}$$

The function  $I$  corresponds to the absolute difference in the probability of reaching the final goal for a given state, according to whether the individual is successful or not at this specific state. In other words, the Morris-importance is given by the impact of being successful or not on the probability of reaching the final goal.

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<sup>7</sup>For the sake of simplicity, we consider the function  $s^+$  defined onto  $S^*$  whereas it should more rigorously be set-valued.

<sup>8</sup>This concept is also used in Magnus and Klaassen (1998), Paserman (2007) and González-Díaz et al. (2012). However, González-Díaz et al. (2012) further use conditional probabilities, which allows them to break down the Morris-importance into the constituent probabilities of winning at the various hierarchical levels of the match.



## 2.2 Stock and allocation of efforts

Now let us assume that the individual has some available stock of efforts. This assumption represents physical and mental capacities to make efforts to increase performance on certain tasks. Many athletes train to increase this ability to concentrate at certain times during their games.<sup>9</sup> If an effort is exerted, the probability of being successful at this state is equal to one. This stock of efforts is independent of the transition probability of an individual. We assume that individuals are able to recognize the importance of a state. Efforts are exhaustible (an effort can be used only once) and limited. Note that individuals have the possibility of choosing whether to use the effort or not and they have no obligation to exhaust their stock of efforts.<sup>10</sup> For instance, if at some state  $s \in \mathcal{S}$ , there exists  $s' \in \mathcal{S}$  such that  $p(s, s') = 1$ , then the individual does not have any strict incentive to make an effort. We define function  $V$  as the probability for an individual reaching his final goal with a given stock of efforts to be used optimally.

**Definition 3.** (*Probability of reaching the final goal with a stock of efforts.*) Consider  $V : \mathbb{N} \times S^* \rightarrow \mathbb{R}$  the probability of reaching the final goal depending on the number of efforts left to make and at a given state.  $V$  is the minimal non-negative solution to the following system:<sup>11</sup>  $\forall s \in S, V(0, s) = P(s)$  and  $\forall k \in \mathbb{N}$  with  $k > 0$ ,

$$\begin{cases} V(k, \{W\}) = 1 \\ \forall s \in S \cup \{L\}, V(s) = \max\{V(k-1, s^+(s)), \sum_{s' \in S^*} p(s, s')V(k, s')\} \end{cases}$$

In order to understand the function displayed in Definition 3, two cases should be considered. First, let us consider that one effort is used in the current state. In this case the individual is successful and the probability of reaching the final goal is equal to the probability of reaching it from the state that the individual reaches after being successful, only with one effort less. Second, if the individual does not use an effort, the probability of reaching the final

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<sup>9</sup>The stock of efforts is exogenous but it could be possible to make it endogenous. Indeed, the agent could decide the stock of efforts before the start of the game. The stock of efforts would depend on a number of anticipated tasks and the cost of creating an exhaustible efforts stock.

<sup>10</sup>Of course, this is a simplification, as in reality individuals may choose finer levels of effort.

<sup>11</sup>Proof of existence and uniqueness is similar to the one for function  $P$  and is therefore omitted.

goal is equal to the expected probability to reach the final goal over the next steps but with no change to his stock of efforts. The individual maximizes over the two cases, as we make the assumption that individuals are infinitely far-sighted optimizers.

We propose in this paper an importance criterion that will depend on how worthy it is to use an effort in a specific state, taking into account the number of efforts left.

**Definition 4.** (*HNV(k)-importance*) *The HNV(k)-importance when  $k > 0$  efforts are left and at state  $s \in \mathcal{S}$  is given by:*

$$HNV(k) = V(k - 1, s^+(s)) - \sum_{s' \in \mathcal{S}^*} p(s, s')V(k, s'). \quad (2)$$

This measure is the difference between the probabilities corresponding to the two cases we described previously: either one effort is used or it is kept to be used later. In other words, this measure determines the incentive to make an effort. When it is positive, it means that it is worth using an effort. When the measure is high, it means that the incentive to use an effort is high.

### 2.3 Differences Between Morris-Importance and HNV-Importance

To sum up, Morris-importance defines the concept of importance as a measure of how closer to the final goal an individual gets when being successful at an intermediate task compared to being unsuccessful. Meanwhile, HNV-importance defines the concept of importance as the incentive to make an effort when it ensures success in an intermediate task. Both definitions rely on the idea that a state should be labeled important when success at this state makes reaching the final goal more probable. Here, we check for the correlations of the two definitions of importance in a simple illustration.

In order to do so, we use the seminal framework of a simplified tennis match as is widely used in the literature. This framework allows a large diversity of point importance – with both definitions – to be observed due to the ratchet effect of game points and set points for instance. More specifically, we consider two different levels of stages, an elementary stage and a crucial

one. To reach the elementary stage, the individual should be successful at a minimum of four acts with at least two acts more than the number of acts for which he is unsuccessful. To reach the crucial stage, the individual should be successful at six intermediate stages. If he is unsuccessful at least at six elementary stages, he fails at a crucial stage. We assume that to reach his goal, the individual should be successful at two crucial stages and be unsuccessful at one crucial stage maximum. We calculate the correlations between Morris-importance and HNV( $k$ )-importance, for  $k$  equal to 1, 2, 3, 4 and 5, considering various arbitrary transition probabilities: 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%. Table 1 depicts these results.

Probability $p$	10%	20%	30%	40%	50%	60%	70%	80%	90%
Correlation (Morris, HNV(1))	0.61	0.43	0.04	-0.12	0.43	-0.12	0.04	0.43	0.61
Correlation (Morris, HNV(2))	0.06	0.04	-0.04	-0.04	0.46	0.07	0.39	0.74	0.83
Correlation (Morris, HNV(3))	0.01	0.03	0.06	0.14	0.48	0.26	0.62	0.89	0.98
Correlation (Morris, HNV(4))	-0.00	0.03	0.07	0.21	0.46	0.36	0.69	0.90	0.97
Correlation (Morris, HNV(5))	-0.01	0.02	0.07	0.24	0.42	0.40	0.71	0.89	0.97

Table 1: Correlations between Morris-importance and HNV( $k$ )-importance, for  $k$  equal to 1, 2, 3, 4 and 5, depending on the transition probability  $p$ .

The correlation between Morris-importance and HNV(1)-importance varies from 0.61 to -0.12. More specifically, the correlation is very low for the transition probabilities  $p = 30%$ , 40%, 60% and 70%. When  $k > 1$ , the two measures are correlated only when the transition probability is very high. For low transition probabilities, correlations are close to zero.

We conclude that the two measures are significantly different and that this difference justifies further investigation as to the validity of the link between importance and performance. However, first, let us build the allocation variables corresponding to each measure of importance.

## 2.4 Allocation Variables

Let us first focus on the ‘‘HNV( $k$ ) 01’’<sup>12</sup> allocation variable. We construct the HNV( $k$ ) 01 allocation variable as follows: we consider that the match starts with players having an initial

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<sup>12</sup>01 stands for either no or one effort.

stock of efforts,  $k$ . Then, at the starting point, we compute whether a player has a positive incentive to use an effort using Definition 4. If that is not the case, the HNV allocation variable is 0 for that point and we proceed to the next point considering that this player keeps the same stock of efforts. If that is the case, then, the HNV allocation variable is 1 and we proceed to the next points of the actual game, only considering that, now, the player has only  $k - 1$  efforts left.

We also consider the case whereby an agent uses Morris-importance to allocate efforts. We construct then an equivalent ‘‘Morris( $\lambda$ ) 01’’ allocation variable, where  $\lambda$  is a threshold. If the Morris-importance is above this threshold, the Morris 01 allocation variable is equal to 1 for that point. Otherwise, the allocation variable is equal to 0. In other words, if the Morris-importance is higher than the threshold, the agent makes an effort. Such a behavior corresponds to a naive allocation of efforts.

As previously, we calculate in the seminal framework of a simplified tennis match the allocation variables Morris( $\lambda$ ) 01 and HNV( $k$ ) 01, for  $p = 0.5$  and for  $k$  equal to 1, 2, 3, 4 and 5, considering various thresholds  $\lambda$ : 0.1, 0.2, 0.3 and 0.4. We then calculate the correlations between Morris( $\lambda$ ) 01 and HNV( $k$ ) 01. Table 2 depicts these results. The allocation variables are significantly different. Indeed, correlation is particularly weak.

Morris threshold $\lambda$	0.1	0.2	0.3	0.4
Correlation (Morris 01, HNV(1) 01)	0.16	0.30	0.09	0.16
Correlation (Morris 01, HNV(2) 01)	0.22	0.33	0.07	0.13
Correlation (Morris 01, HNV(3) 01)	0.26	0.25	0.05	0.05
Correlation (Morris 01, HNV(4) 01)	0.34	0.25	0.02	0.05
Correlation (Morris 01, HNV(5) 01)	0.37	0.20	0.01	0.04

Table 2: Correlations between Morris 01 and HNV( $k$ ) 01 for  $p = 0.5$ .

In the remainder of this article, we use an experiment to check which definition of importance is better at explaining performance.

## 3 Experimental Design and Procedures

### 3.1 Experimental Design

In order to test these different approaches of importance and analyze which criterion has the highest predictive power of performance in a real effort task, we designed a laboratory experiment. The experiment consists of two treatments, the Human treatment and the Robot treatment. We used a between-subject design. The main difference between these two treatments is that when an individual faces a robot opponent in our game he does not have to form beliefs about how the other individual will use his efforts strategically. Let us describe each of these treatments successively.

**The Human treatment** In the Human treatment we pair participants at the beginning of the session. Each pair member has to compete to win a prize. To win the prize, the two competitors have to perform several rounds of a real-effort task. This task involves using the mouse pointer to reach the center of a target that is displayed on the computer screen (see Figure 1). Participants have to shoot as accurately as possible in the center of the target. The measure of performance is given by the Euclidean distance in pixels between the impact of the shot and the center of the target. The smaller the distance is, the better the performance. The difficulty of the task comes from a continuous perturbation of the mouse position that is random in each trial (giving the impression of a trembling hand). The perturbation is different across subjects but is drawn from the same distribution, so that the difficulty is *ex ante* the same for each subject. In a trial, each participant has 8 seconds maximum to shoot. If the shot has not been performed in 8 seconds, it is considered as missing in the current trial.

The payoffs in the game depend on the outcome of the competition. The winner of the game earns 20 Euros while the loser gets nothing. There is an opportunity cost of exerting no effort since earnings are likely to be zero in that case. The game consists of several trials, rounds and sets. In a given trial, the competitor with the best performance (that is to say, the shortest distance to the center of the target) scores one point. In case of a tie between the two participants, a random draw determines which one is awarded the point. The first

The screenshot displays a task interface with a target on the left and instructions on the right. The target consists of concentric circles in blue, yellow, green, and red. Below the target, the text "Chrono: 7,20" is visible. The instructions section is titled "Instructions" and contains the following text:

Your computer : R1C1

The game will start after 10 practice shots.

The first of the two co-participants who wins 2 sets wins the game.

The first of the two co-participants who wins 6 rounds wins the set.

The first of the two co-participants who earns at least 4 points with at least 2 points ahead wins the round.

The co-participant who wins the game earns €20 in addition to the participation fee. The opponent earns only the participation fee.

At the bottom of the interface is a table with the following data:

	Set	Round	Point
YOU	1	5	3
OPP	1	5	3

Figure 1: Screenshot of the task.

of the two competitors to win at least 4 points with at least 2 points ahead of the opponent wins the round. The first of the two competitors who wins 6 rounds takes the set. The first of the two competitors who wins 2 sets takes the match. There is one match in each session. As indicated in Figure 1, participants are permanently informed on the number of points, rounds and sets they and their opponent have won so far.

Before the game starts, participants can make 5 test shots and 10 practice shots and receive feedback on the distance to the target after each shot. The test shots are intended to familiarize them with the task. The practice shots are used to calculate each participant's ability and this is made common information. We acknowledge that this measure may be somewhat noisy since the practice shots are not incentivized. Our motivation is twofold: i) not creating differences in earnings between players before the beginning of the competition that could affect their behavior during the game, and ii) not deceiving participants about the use of their performance in these practice shots for calculating their ability level relative to that of their opponent.<sup>13</sup> This measure aims at capturing the permanent ability of the participant, independent of his critical ability (*i.e.* his capacity to recognize important points and focus his efforts on these important points).<sup>14</sup> The program compares the participant's performance in each of the practice shots to the performance of his opponent, taking into account all possible combinations of these shots (ignoring the shots not completed before time elapsed). At the beginning of the actual game, participants receive information about the theoretical number of chances out of 100 that they should win a point over their opponent for a given shot.<sup>15</sup>

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<sup>13</sup>We tested whether the average individual performance in these practice rounds differs across treatments. Performance in the practice shots is similar in the Human treatment (where people could possibly behave strategically to misrepresent their true ability; mean = 9.72) and in the Robot treatment (where they have no reason to behave strategically, as explained below, mean = 8.07) (two-tailed Mann-Whitney,  $z = 0.261$ ,  $p = 0.794$ ). Nevertheless, the lack of significant difference might hide the fact that in the Human treatment some subjects do their best while others provide strategically little effort. We reject this, as a Kolmogorov-Smirnov test shows that there is no significant difference in the distribution of performance in the practice shots across treatments (exact  $p = 0.914$ ).

<sup>14</sup>We assume that participants do not consider their stock of efforts when performing the practice rounds, in contrast to the competition game, because there are only ten practice shots and each shot is independent from the others (there is no notion of set or match during the practice). Thus, the measure of relative ability in the practice shots is assumed to be comparable for building our two measures of importance. The Morris-importance criterion should not be more sensitive to the practice round information than the HNV-importance criterion.

<sup>15</sup>Indeed, in most actual sport or occupational tournaments, when they start competing, competitors are aware of their relative ability compared to that of their opponents, based on previous records of performance.

**The Robot treatment** In the Robot treatment participants are informed that they are paired with a robot. It is also made common knowledge that the robot does not shoot at random: we assigned the performances of participants in previous sessions to each robot. This means that each shot is an actual shot, but played independently against the current human opponent. The robot's shot can also come from any period of the match (*i.e.* when the human subject plays a match point, the robot's shot is not selected among the previous match points but among all points). Here, a human participant should try to shoot as accurately as possible regardless of his beliefs about his opponent's play since this opponent cannot elaborate a strategy in response to his own play. The rules of the game are similar in this treatment to that used in the Human treatment. Like in the Human treatment, participants receive information at the beginning of the game about the theoretical number of chances out of 100 that they should win a point over their opponent. The difference is that the program compares the participant's performance in each of the practice shots to the performance in the same practice shots of different subjects in previous sessions, taking into account all possible combinations of these shots.

To study the impact of stress on performance in this game, we also measured emotional arousal continuously during the game. This gives us an index of stress. We were able to record electrophysiological measures simultaneously for 12 participants per session (in total, 48 subjects were recorded in the Human treatment and 24 in the Robot treatment). Some of the participants were not recorded to control that recording emotions did not influence performance (in fact we show below that it did not). We take the Skin Conductance Responses (SCR) as a measure of physiological arousal associated with an emotional state. SCR were continuously recorded until the end of the session, in a noiseless environment with a stable temperature set at 21°C. Skin conductance is analyzed in response to three events. (a) The first is during the time interval between the display of the target and the moment the shot is taken. (b) The second event of interest is the time of reception of feedback about one's own performance. (c) The third event is the time of reception of feedback on the opponent's performance (thus, on who wins the point). We imposed a minimum of 5 seconds between



the second and third events when sending feedback to the subjects in order to avoid the overlapping of emotional arousals related to two different events. For the first event, SCR are analyzed within a time window with variable duration across subjects and trials since shots are self-paced (between 5 and 8 seconds).<sup>16</sup> For the next two events, the time window is set at one to three seconds after the onset of these events to capture the onset of the response and determine whether there is a significant arousal. While emotional arousal is detected within the time window, the SCR magnitude may be given by observation after the time window. The data analysis is based on this magnitude.<sup>17</sup>

At the end of the experiment, a brief demographic questionnaire was administered, including questions on gender and age. We also asked participants if they were tennis players since familiarity with its rules may possibly help participants in our game.

## 3.2 Procedures

The computerized experiment was conducted at GATE-LAB, Lyon, France. 103 participants were recruited from local engineering and business schools, using ORSEE (Greiner (2015)). We ran four sessions for the Human treatment and two for the Robot treatment, with respectively 70 and 33 participants. Summary statistics on participants are reported in Table 3. Based on non-parametric statistics, the composition of the two treatment samples does not differ significantly in terms of percentage of subjects with SCR measured, gender, age, practice of tennis and ability in the game. Permanent ability (distinct from critical ability) is measured as the average distance to the center of the target in the ten practice shots (excluding the shots after allowed time).

Upon arrival, participants drew a tag from a bag that determined their random assignment

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<sup>16</sup>If the participant shoots in less than 5 seconds after the target appears on the screen, the window of analysis includes a minimum of five seconds. If the participant shoots between five and eight seconds, the window analysis is the time between the display of the target and the timing of the shot.

<sup>17</sup>The signal was low-pass filtered at 0.5Hz offline, using a 5th order Butterworth low-pass digital filter. The onset and peak of the SCR were detected when the first derivative of the filtered signal changed sign thanks to a routine written in Matlab (The MathWorks Inc., USA). Onsets were identified by a negative to positive zero crossing. Peaks were identified by a positive to negative zero crossing. The SCR amplitude was calculated as the difference between the signal amplitude at the peak and the onset times. It was thresholded at 0.02  $\mu$ S. The whole signal was visually inspected prior to further analysis and ectopic response was removed. The analysis assigns zero amplitude to the subjects without a measurable response (Dawson et al. (2007)).

	All treatments	Human treatment	Robot treatment
Number of sessions	6	4	2
Number of participants	103	70	33
Percentage of players with SCR measured	69.90	68.57	72.73 ns PT
Percentage of males	40.78	44.29	33.33 ns PT
Mean age	21.68 (3.18)	21.77 (3.45)	21.48 (2.54) ns MW
Percentage with tennis experience	28.16	27.14	30.33 ns PT
Mean distance in the 10 practice shots	7.80 (0.77)	7.73 (0.75)	7.95 (0.78) ns MW

Notes: Standard deviations are in parentheses. ns: non significant. PT: proportion test, with one individual as one independent observation. MW: Mann-Whitney tests. All tests are two-sided.

Table 3: Summary statistics on participants.

to a computer terminal. Next, each participant whose SCR were measured had to wash their hands with a neutral soap. Then, an experimentalist put electrodes on the non-dominant hand to be kept until the end of the session. After checking the quality of the signal recording, the set of instructions was distributed to all participants and read aloud. The participants’ understanding was checked by means of a questionnaire conducted in private.

On average, a session lasted about 60 minutes (a bit longer for the subjects for which we measured SCR due to the preparation procedures), including payment. The participants were paid their earnings from the game (either 20 euros or 0) in addition to a 5 euros show-up fee. On average, participants earned 14.90 euros (S.D.=10.05). We paid participants individually in cash and in private in a separate room immediately after the end of the session.

## 4 Experimental Results

Table 4 gives a brief overview of descriptive statistics relative to the two treatments. The last column reports non-parametric tests comparing the two treatments. In these tests, one mean value for each individual for the whole game is taken as one independent observation. In the data analysis our main variable of interest is the subject’s performance, as we cannot observe effort directly. As mentioned earlier, we measure performance by the Euclidian distance in pixels between the impact of the shot and the center of the target.

Table 4 indicates a significant difference between treatments in terms of performance in

	All treatments	Human treatment	Robot treatment
Mean distance to the target in practice rounds (in pixels)	9.19 (8.37)	9.72 (10.03)	8.07 (2.11) ns MW
Mean distance to the target (in pixels)	7.68 (5.47)	7.60 (5.15)	7.86 (6.08) ** MW
Mean time to shoot (in milliseconds)	3314.56 (1611.42)	3423.07 (1687.53)	3087.16 (1412.30) ns MW
Mean number of shots	153.54 (42.95)	152.94 (42.79)	154.82 (43.92) ns MW
Percentage round shots (i's advantage)	12.68	12.67	12.70 ns MW
Percentage set shots (i's advantage)	0.94	0.96	0.88 ns MW
Percentage match shots (i's advantage)	0.70	0.72	0.67 ns MW
Percentage of winning subjects	49.51	50.00	48.48 ns binomial test
Mean Morris	0.05 (0.06)	0.05 (0.06)	0.05 (0.06) ns MW
Mean HNV	0.09 (0.29)	0.09 (0.28)	0.10 (0.30) ns MW
Mean SCR amplitude at presentation of the target	0.03 (0.12)	0.02 (0.09)	0.04 (0.17) ns MW
Mean SCR amplitude at feedback on own score	0.122 (0.178)	0.113 (0.164)	0.145 (0.208) ns MW
Mean SCR amplitude at feedback on trial outcome	0.110 (0.178)	0.103 (0.175)	0.126 (0.183) ns MW

Notes: Standard deviations are in parentheses. ns: non significant. MW: Mann-Whitney tests. All tests are two-sided and take the mean value for one individual as one independent observation.

Table 4: Summary statistics on the games.

the game ( $p=0.046$ ), but no difference regarding performance in the practice rounds, time to shoot, duration of the match, percentage of round/set and game shots to the advantage of the individual, and emotional arousal. The lower average performance in the Human treatment could result from social preferences that cannot play any role in the Robot treatment, as players know that exerting more effort increases the chance that their human opponent will earn zero. We introduce our first result.

**Result 1:** The approach based on the Morris criterion of importance fails to predict participants' shot performance. The nature of the shot (round/set/match shots vs. regular shots) has limited predictive value. Players do not choke under pressure.

*Support to Result 1.* To compare the predictive values of our different importance criteria, we use an econometric analysis in which the dependent variable is the player's performance captured by the distance of the shot from the center of the target in each trial. We estimate linear regressions<sup>18</sup> with robust standard errors clustered at the individual level. In all the econometric models reported in the remainder of this section, the independent variables include the complexity of the current shot, the time to shoot and the shot number in the game. The "Distance practice" variable is the mean distance to the center of the target in the ten practice shots: the higher this distance is, the lower is the player's permanent ability. As explained earlier, the relative ability variable is built by comparing the participant's performance in each practice shot to the performance of his opponent, accounting for all possible combinations of these shots. Complexity is measured by the sum of the net perturbations of the trajectory during 250 milliseconds before the shot.<sup>19</sup> Although players are not aware *ex ante* of the complexity of the shot, we include this variable in the regression since it is expected to influence the distance to the target in that shot. We control for whether the player's electrodermal responses were recorded or not and for the magnitude of the emotional arousal at the time of

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<sup>18</sup>We do not need to use tobit since only 0.41% of the data are censored at 0.

<sup>19</sup>Every 50ms, we draw two integer numbers,  $lx$  and  $ly$  in the interval  $[-5;5]$  with uniform probability. The player's pointer is modified by  $lx$  pixels on the x-axis and  $ly$  pixels on the y-axis. Let  $Lx = (lx_i)_{i \in [1;5]}$  be the sequence of the five values of  $lx$  drawn before the player shot and  $Ly = (ly_i)_{i \in [1;5]}$  be the sequence of the five values of  $ly$  drawn before the player shot. The value we report is  $S = \sqrt{((\sum_{i=1}^5 lx_i)^2 + (\sum_{i=1}^5 ly_i)^2)}$ . Then,  $S$  is the distance between the positions of the pointer 0.25 seconds before the player's shot and at the time of the shot that is generated by the noise alone.

the shot.<sup>20</sup> We also include controls for gender, age and practice of tennis.

First, we consider a notion of effort assignment based on the nature of the shot. Precisely, we test whether the distance to the target is affected by the fact that relative performance for that shot determines whether the player or his opponent wins either a round, a set or the match, compared to a regular shot (omitted category). The first three columns of Table 5 report these regressions for the two treatments pooled together (model (1)), the Human treatment (model (2)) and the Robot treatment (model (3)). In model (1), we include a dummy variable indicating whether the player is interacting with a human opponent or with a robot.

In Table 5, model (2) indicates that, in most cases, round, set and match shots have no specific impact on performance compared to regular shots. Exceptions in the Human treatment (robust to many specifications) are that performance is significantly better when it determines whether the player will win the round or whether the opponent will win the match. In the Robot treatment, it is marginally significantly better when it decides whether the opponent will win the round.

Our second measure of optimal effort assignment is based on the Morris criterion. It is calculated for each shot based on the percentage of ex ante chances each competitor has of winning the game considering his relative performance in the ten practice shots. The last two columns of Table 5 report the estimates of the model in which we consider the value of the Morris-importance for each shot instead of the stake for the shot. Model (4) is for the Human treatment and model (5) for the Robot treatment. These two models show that Morris-importance attracts the predicted negative sign but is far from reaching standard significance levels in any treatment. Other specifications, evoked later in the section, show that this result is robust. We then consider HNV-importance and present our second result.

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<sup>20</sup>We also tested the potential influence on the current distance of the emotional arousal experienced during the previous shot at the time of the feedback on one's score and on the trial's outcome. This requires dropping the observations relative to the first shot in the game. Since these two SCR measures were never significant, we do not include these variables in the regressions reported here and keep the data of all periods. Note also that in all regressions, the SCR magnitude is used as a control variable and not as an outcome variable. To test whether a higher effort could generate a higher SCR level, we have also estimated a variety of regression models with clustering at the individual level with the SCR magnitude as the dependent variable and performance as an independent variable. Regardless of the specification used, effort never correlates significantly with the SCR magnitude and it is far from reaching standard significance levels (lowest  $p$ -value = 0.18).

	Dep. variable: Distance to center	Nature of the shoot			Morris criterion	
		All (1)	Human treatment (2)	Robot treatment (3)	Human treatment (4)	Robot treatment (5)
	Human opponent	6.692*** (1.987)	-	-	-	-
	Complexity	0.634*** (0.011)	0.632*** (0.015)	0.640*** (0.018)	0.631*** (0.015)	0.640*** (0.018)
	Round shot for i	-0.130 (0.126)	-0.329*** (0.104)	0.288 (0.312)	-	-
	Set shot for i	-0.339 (0.243)	-0.256 (0.303)	-0.502 (0.405)	-	-
	Match shot for i	0.097 (0.255)	0.244 (0.288)	-0.144 (0.512)	-	-
	Round shot for j	-0.101 (0.080)	0.003 (0.086)	-0.309* (0.159)	-	-
	Set shot for j	-0.321 (0.251)	-0.398 (0.321)	-0.219 (0.407)	-	-
	Match shot for j	-0.569** (0.248)	-1.025*** (0.255)	0.381 (0.506)	-	-
	Morris criterion	-	-	-	-0.037 (0.526)	-2.115 (2.283)
	Distance Practice	0.948*** (0.097)	0.264** (0.115)	0.981*** (0.103)	0.266** (0.115)	0.952*** (0.084)
	Distance Practice*Human opponent	-0.675*** (0.158)	-	-	-	-
	Relative ability	0.439 (1.205)	-2.757** (1.204)	0.046 (1.109)	-2.687** (1.180)	0.281 (1.113)
	Relative ability*Human opponent	-3.051* (1.824)	-	-	-	-
	Time to shoot	<-0.001 (<0.001)	<0.001 (<0.001)	<-0.001 (<0.001)	<0.001 (<0.001)	<-0.001 (<0.001)
	Shot number	<-0.001 (0.001)	-0.001 (0.001)	<0.001 (0.002)	-0.001 (0.001)	0.002 (0.003)
	SCR measure	-0.085 (0.059)	-0.052 (0.071)	-0.126 (0.099)	-0.051 (0.071)	-0.144 (0.098)
	SCR magnitude	0.542* (0.297)	-0.101 (0.326)	0.923*** (0.309)	-0.104 (0.325)	0.928*** (0.302)
	Male	-0.059 (0.056)	-0.011 (0.067)	-0.073 (0.131)	-0.009 (0.066)	-0.075 (0.126)
	Age	0.014*** (0.004)	0.021*** (0.006)	-0.019 (0.012)	0.021*** (0.006)	-0.020 (0.014)
	Tennis	-0.107 (0.066)	-0.113 (0.082)	-0.080 (0.092)	-0.111 (0.082)	-0.062 (0.083)
	Constant	-4.984*** (1.223)	1.627 (1.262)	-4.164*** (1.207)	1.553 (1.256)	-4.030*** (1.043)
	Nb observations (clusters)	15740 (103)	10640 (70)	5100 (33)	10640 (70)	5100 (33)
	F	406.20	270.41	395.58	345.04	412.44
	p>F	<0.001	<0.001	<0.001	<0.001	<0.001
	R2	0.219	0.237	0.193	0.236	0.193

Table 5: Determinants of performance, including the nature of the shot or Morris-importance.

**Result 2:** The HNV-importance for the optimal assignment of efforts predicts players' performance. This finding holds in the Human treatment when assuming that all players are endowed with the same stock of efforts and in both treatments when allowing each player to differ in his stock of efforts.

*Support for Result 2.* In a dynamic setting, we consider that all players start the game with a stock of either 10, 20, 30, 40 or 50 efforts to assign during the match. The player does not take into account the other player's response to his own play. We compute dynamically along the match on which points a subject should optimally use these 10, 20, 30, 40 or 50 efforts, based on his relative ability in the ten practice shots and knowing the actual duration of the game against his actual opponent. Indeed, we assume that players are able to form an expectation about the overall duration of the match, knowing their relative ability. We consider for each trial the incentive players have to use one effort, considering the stock of efforts left. For each initial stock of efforts among 10, 20, 30, 40, 50 we build the HNV-importance variable that takes value 1 or 0, depending on whether the effort for the given stock should be invested or not in the current shot, as determined by our model.

In Table 6, we estimate five models explaining the distance to the target of the current shot in the Human treatment, one for each initial stock of optimal effort assignment between 10 and 50. We add the HNV criterion to the previous independent variables (complexity, distance practice, relative ability, time to shoot, shot number, recording of SCR, magnitude of SCR, gender, age, and practice of tennis). Table A1 in Appendix displays the same models for the Robot treatment.

In all models but one (when we consider 40 optimal efforts to assign) in the Human treatment, the HNV criterion predicts the player's performance at the 5% or at the 1% significance level. The coefficient is higher when we consider 50 optimal efforts to assign: in that case accuracy is higher. In contrast, Table A1 in the Appendix shows that in the Robot treatment the HNV allocation variable does not impact performance.<sup>21</sup> This surprising finding indicates

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<sup>21</sup>We also estimated models 4 and 5 in Table 5 and all models of Table 6 without including the Distance Practice and Relative Ability variables among the independent variables. This does not change our results (see Table A2 in Appendix). Note also that all our regressions have been conducted with cluster adjusted standard errors at the individual level instead of using GLS models with fixed effects. This is usually considered as more

Dep. variable: Distance to center	10 efforts (1)	20 efforts (2)	30 efforts (3)	40 efforts (4)	50 efforts (5)
Complexity	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)
HNV allocation variable	-0.305** (0.129)	-0.326*** (0.115)	-0.358*** (0.097)	-0.182* (0.097)	-0.984*** (0.261)
Distance Practice	0.265** (0.115)	0.263** (0.115)	0.259** (0.113)	0.260** (0.114)	0.265** (0.116)
Relative ability	-2.689** (1.187)	-2.782** (1.177)	-2.894** (1.171)	-2.998** (1.203)	-2.795** (1.199)
Time to shoot	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)
Shot number	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)
SCR measure	-0.052 (0.070)	-0.054 (0.070)	-0.047 (0.070)	-0.054 (0.071)	-0.051 (0.070)
SCR magnitude	-0.099 (0.325)	-0.098 (0.325)	-0.113 (0.325)	-0.094 (0.327)	-0.103 (0.328)
Male	-0.008 (0.066)	-0.010 (0.066)	-0.008 (0.066)	-0.004 (0.067)	-0.013 (0.066)
Age	0.021*** (0.006)	0.021*** (0.006)	0.021*** (0.006)	0.022*** (0.006)	0.021*** (0.006)
Tennis	-0.114 (0.081)	-0.113 (0.081)	-0.110 (0.081)	-0.110 (0.081)	-0.114 (0.081)
Constant	1.568 (1.568)	1.656 (1.260)	1.773 (1.245)	1.761 (1.265)	1.608 (1.270)
Nb observations (clusters)	10640 (70)	10640 (70)	10640 (70)	10640 (70)	10640 (70)
F	342.41	342.35	348.27	345.93	361.75
p>F	<0.001	<0.001	<0.001	<0.001	<0.001
R2	0.237	0.237	0.237	0.237	0.237

Notes: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\*, \*\* and \* indicate significance at the 1% level, 5% level and 10% level, respectively.

Table 6: Determinants of performance in the Human treatment, based on the homogeneous HNV-importance.



that when the player should rationally use one effort from his stock according to HNV theory, this indeed improves his performance by reducing the distance to the target, but exclusively when the player interacts with a human opponent.<sup>22</sup> This suggests that when interacting with a robot, the impossibility of predicting one’s opponent effort in a specific moment of the match affects the ability of a player to assign his efforts according to the HNV-importance.

Notice that in the previous analyzes, we estimated the predictive power of the Morris, HNV and the nature-of-the-shot measures in separate regressions in order not to bias the coefficients (since some variables are used in each of these measures to calculate importance). Nevertheless, we have added Table A3 in Appendix similar to Table 6 except that we include both the Morris-importance and the HNV-importance criteria. The main message is that the Morris-importance criterion remains insignificant (it even has the opposite sign as predicted) while the HNV-importance criterion remains significant like in the initial regressions reported in Table 6. Thus, individuals perform better at shots predicted by the HNV-importance criterion than by the Morris-importance criterion. In addition, we estimated models in which we include the HNV-importance criterion controlling for round shots, set shots, match shots in the same regressions. Not surprisingly, the significance of the HNV-importance criterion is lower than in the original regressions, but it remains significant for stocks of effort of 30 and 50 units (at the 5% and 1% levels, respectively) (see Table A4 in Appendix).

In each regression reported in Table 6, we forced each player to use the same initial stock of efforts. We now relax this constraint by allowing for individual heterogeneity in optimal effort assignment. In other words, we now consider the heterogeneity in individuals’ critical ability, as shown by González-Díaz et al. (2012) concerning tennis players. To do so, we estimate for each individual which initial stock of efforts, between 10 and 50, best fits his distance to the

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efficient and this accounts for within-cluster correlation and heteroskedasticity; we included a few observable individual characteristics as controls to test whether ability, gender or age affect performance specifically. However, we also ran GLS models with fixed effects to control for both observable and unobservable time-invariant individual characteristics. The Morris-importance criterion does not become more significant. The HNV-importance criterion in the Human treatment is less precisely estimated than in the original regressions (it is never significant in the Robot treatment, like before). It remains significant for stocks of efforts of 20, 30 and 50 (at the 5%, 1% and 10%, respectively); the  $p$ -value of the coefficients for stocks of efforts of 10 and 40 does not reach standard levels of significance ( $p = 0.121$  and  $0.111$ , respectively). These estimations are available upon request.

<sup>22</sup>Note that we also tested the same model considering the assignment of more than 50 units of effort. The HNV allocation variable remains significant at the 1% level. To save space, we omit these regressions here.

target throughout the game, with a linear model and robust standard errors. We consider five estimations for each individual, one for each possible initial stock of efforts, and include as independent variables the HNV allocation variable for that stock, the complexity of the current shot, the time to shoot and the shot number. We compare the five regressions for each individual and retain the model -therefore the initial stock of optimal efforts for this player- that gives the highest t-value to the HNV allocation variable.<sup>23</sup> Next, in Table 7 we report three regressions of the distance to the target, one for the treatments pooled together (1), one for the Human treatment (2) and one for the Robot treatment (3). The independent variables are the same as in Table 6, except that the HNV criterion now corresponds to different stocks of optimal effort assignment across players, as determined by the individual regressions.

Table 7 shows that if we allow for individual heterogeneity in the endowment in terms of effort stock, a shot with a higher importance according to the HNV allocation variable significantly increases the player's performance. This is observed regardless of whether the opponent is a human (model (2)) or a robot (model (3)). While the findings of Tables 6 and 7 are consistent, Table 7 contradicts those of Table A1. This suggests that players behave more heterogeneously when they are facing a robot, as a general approach of effort assignment fails to predict performance in this case. We doubt that this is due to the randomization procedure itself: subjects were assigned randomly to a treatment or another and most descriptive variables do not differ significantly across treatments; there is no reason to expect that subjects had originally different stocks of efforts in the two treatments. In contrast, it is possible that individuals play differently against a robot than against a human opponent. For example, some individuals may find it more difficult to motivate themselves to play against a robot. Also, when playing against a human opponent, competitiveness may become more salient, which may increase individual heterogeneity. At this stage, we can only speculate and further investigations would be needed to identify the explanation of these differences.

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<sup>23</sup>For some individuals we have to reject the five regressions and assign to the player a missing HNV allocation variable. This occurs when the HNV allocation variable receives a positive coefficient (indicating that performance decreases when the point is more important in the sense of the HNV model). This corresponds to 7.14% of the players in the Human treatment and to 9.09% of the players in the Robot treatment (the difference is not statistically significant according to a proportion test). These observations are kept in the regressions and we include a dummy variable ("Missing HNV allocation") to the other independent variables.

Dep. variable:	All treatments	Human treatment	Robot treatment
Distance to center	(1)	(2)	(3)
Human opponent	5.337*** (1.791)	-	-
Complexity	0.640***(0.017)	0.630***(0.015)	0.640***(0.018)
Complexity*human	-0.010 (0.023)	-	-
HNV allocation variable	-0.903***(0.173)	-0.898***(0.075)	-0.903***(0.175)
HNV allocation variable*human	0.005 (0.188)	-	-
Missing HNV allocation variable	-0.158* (0.092)	-0.185** (0.072)	-0.158* (0.093)
Missing*human	-0.027 (0.117)	-	-
Distance Practice	0.954*** (0.085)	0.249** (0.123)	0.954*** (0.086)
Distance Practice*human	-0.706***(0.150)	-	-
Relative ability	-0.778 (1.273)	-2.729** (1.257)	-0.778 (1.287)
Relative ability *human	-1.951 (1.787)	-	-
Time to shoot	<-0.001 (<0.001)	<0.001 (<0.001)	<-0.001 (<0.001)
Time to shoot*human	<0.001 (<0.001)	-	-
Shot number	<0.001 (0.002)	-0.001 (0.001)	<0.001 (0.002)
Shot number*human	-0.002 (0.002)	-	-
SCR measure	-0.105 (0.103)	-0.070 (0.074)	-0.105 (0.104)
SCR measure *human	0.035 (0.126)	-	-
SCR magnitude	0.893***(0.289)	-0.110 (0.326)	0.893***(0.292)
SCR magnitude *human	-1.003** (0.434)	-	-
Male	-0.038 (0.123)	0.013 (0.070)	-0.038 (0.125)
Male*human	0.051 (0.141)	-	-
Age	-0.016 (0.012)	0.021*** (0.006)	-0.016 (0.012)
Age*human	0.037*** (0.013)	-	-
Tennis	-0.076 (0.095)	-0.106 (0.082)	-0.076 (0.096)
Tennis*human	-0.030 (0.125)	-	-
Constant	-3.539*** (1.182)	1.798 (1.349)	-3.539*** (1.195)
Nb observations (clusters)	15740 (103)	10640 (70)	5100 (33)
F	400.79	328.18	445.35
p>F	<0.001	<0.001	<0.001
R2	0.221	0.239	0.194

Note: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\*, \*\* and \* indicate significance at the 1% level, 5% level and 10% level, respectively.

Table 7: Determinants of performance in the Human treatment, based on the heterogeneous HNV-importance.

We wish to determine whether Result 2 derives from the possibility of allocating efforts or from the fact that the agent takes into account the option-value to decide whether he makes an effort or not. The allocation variable  $\text{Morris}(\lambda)$  01 determined in Section 2 corresponds to a naive allocation of efforts. Therefore, we determine whether the allocation variable  $\text{Morris}(\lambda)$  01 explains performance. In Table 8, we estimate four models explaining the distance to the target of the current shot in the Human treatment and in the Robot treatment. We consider the following thresholds: 0.1, 0.2, 0.3 and 0.4. We demonstrate that  $\text{Morris}(\lambda)$  01 is not significant and then does not explain performance. We conclude that Result 2 does not come from the possibility of allocating efforts but from the method used to calculate how to allocate effort. We finally introduce our last result.

Dep. variable: Distance to center	Human treatment				Robot treatment			
	$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$	$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$
Complexity	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.640*** (0.018)	0.640*** (0.018)	0.640*** (0.018)	0.640*** (0.018)
$\text{Morris}(\lambda)$ 01	-0.013 (0.095)	-0.205 (0.194)	-0.112 (0.156)	-0.077 (0.234)	-0.101 (0.245)	-0.219 (0.270)	-0.097 (0.492)	0.254 (1.094)
Distance in practice	0.266** (0.115)	0.266** (0.115)	0.266** (0.115)	0.266** (0.115)	0.974*** (0.096)	0.976*** (0.099)	0.976*** (0.099)	0.975*** (0.099)
Relative ability	-2.684** (1.177)	-2.685** (1.177)	-2.684** (1.176)	-2.686** (1.178)	0.158 (1.134)	0.162 (1.142)	0.162 (1.142)	0.149 (1.155)
Time to shoot	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<-0.001 (<-0.001)	<-0.001 (<-0.001)	<-0.001 (<-0.001)	<-0.001 (<-0.001)
Shot number	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)
SCR measure	-0.051 (0.070)	-0.051 (0.070)	-0.051 (0.070)	-0.051 (0.070)	-0.131 (0.096)	-0.130 (0.096)	-0.130 (0.096)	-0.129 (0.096)
SCR amplitude	-0.104 (0.324)	-0.108 (0.324)	-0.104 (0.325)	-0.104 (0.325)	0.925*** (0.304)	0.908*** (0.304)	0.912*** (0.306)	0.916*** (0.304)
Male	-0.009 (0.066)	-0.010 (0.066)	-0.009 (0.066)	-0.009 (0.066)	-0.069 (0.129)	-0.067 (0.131)	-0.068 (0.130)	-0.066 (0.131)
Age	0.021*** (0.006)	0.021*** (0.006)	0.021*** (0.006)	0.021*** (0.006)	-0.019 (0.012)	-0.019 (0.012)	-0.018 (0.012)	-0.019 (0.012)
Tennis	-0.111 (0.082)	-0.110 (0.081)	-0.112 (0.081)	-0.112 (0.081)	-0.077 (0.088)	-0.078 (0.090)	-0.079 (0.091)	-0.078 (0.090)
Constant	1.547 (1.257)	1.540 (1.251)	1.548 (1.252)	1.547 (1.255)	-4.201*** (1.135)	-4.221*** (1.154)	-4.214*** (1.159)	-4.201*** (1.158)
Nb observations	10640 (70)	10640 (70)	10640 (70)	10640 (70)	5100 (33)	5100 (33)	5100 (33)	5100 (33)
F	343.49	346.20	384.20	374.94	470.35	470.35	466.60	493.39
p>F	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
R2	0.235	0.236	0.236	0.236	0.192	0.192	0.192	0.192

Note: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\* indicates significance at the 1% level.

Table 8: Determinants of performance, with  $\text{Morris}(\lambda)$  01 allocation variable

**Result 3:** Emotional arousal hinders performance only when players are facing a robot, possibly because they cannot predict their opponent’s strategy.

*Support for Result 3.* Tables 5 to 7 show that having one’s emotions recorded does not impact performance. For the average player, all else being constant, having a robot opponent has a positive impact on performance, except for those subjects who experience a greater SCR magnitude. In contrast, SCR never affects performance in the Human treatment. A possible explanation is that on average individuals feel less discouraged when losing points when they know they can ignore the strategy of the opponent since the robot is not reacting to their play. But the sub-sample of players who are more emotionally aroused when playing against a robot may see the competitive situation as more threatening than when opposed to a human, which affects their performance negatively. Blascovich et al. (2004) and Moore et al. (2012) for example found a correlation between perception of threat, physiological reaction and performance in sport competitions; Buckert et al. (2015) have shown that perceiving competition as a threat tends to decrease a player’s performance in the lab. A possible interpretation is that in our game, emotionally aroused players may be those who see a competition against a robot as more threatening than a competition against a human because they cannot predict the importance of the shot for the robot opponent.

Finally, it should be noted that almost all models show that performance decreases with the level of complexity of the shot, the player’s age and the human opposition (in the Human treatment), and it improves with the player’s permanent absolute and relative ability. Other controls are never significant.

## 5 Conclusion

Successive tasks often do not have the same importance when it comes to achieving a final goal. A clear illustration is given by a tennis match but other examples can be found in the occupational domain. The present paper assesses whether performance increases according to the importance of the task to be undertaken by comparing various theories. In this paper, we propose to measure the importance of a task not by the Morris-importance criterion but by

the HNV-importance criterion. The latter assumes that the agent has a stock of exhaustible efforts and chooses the ideal moment to make an effort. Our criterion of HNV-importance takes into account the trade-off between the stakes and the option value for determining whether it is worthwhile to use an effort or not on a given task. An effort is used when the HNV-importance is higher. We test experimentally these two approaches to importance, as well as a simple measure of importance based on critical shots (round/set/match shots). The results show that the HNV allocation variable outperforms the Morris-importance, while the latter always fails at predicting the players' performance. The nature of the shot has predictive value only for the round shot for the individual and the match shot for the opponent. Moreover, we do not find clear evidence of the existence of choking under pressure: stress, as measured by the Skin Conductance Responses, does not affect performance when interacting with a human opponent.

This study could of course be extended in several ways. In particular, it could be interesting to consider the case under which, after a certain delay, the agent can regain efforts. For example, studies have shown the existence of a momentum effect for the winner of a point in dynamic contests (Gauriot et al. (2014)). The idea that success breeds success could be captured in our model by an increase of the stock of efforts left during the match depending on success at previous important points. It might also be interesting to investigate the relation between efforts and tiredness. Indeed, an effort increases performance in the current task but it may also decrease performance in the following tasks, decreasing the mean performance of the agent in the rest of the competition. The agent then would face a trade-off: indeed, making an effort may shorten the competition but it may also negatively affect future performance if the competition lasts. This is left for further investigation.

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## A Appendices

### A.1 Illustration of Morris-importance and $\text{HNV}(k)$ -importance for tennis scores

Consider a tennis match between player 1 and player 2. Obviously, they both have the objective to win the match. We do not consider service and receive.

#### A.1.1 Illustration of Morris-importance and $\text{HNV}(k)$ -importance for a single game

We first focus on a single game and we assume that the player who wins the game is declared victorious. Note that a margin of two points is required. We assume that the probability to win one point is the same for both players ( $p = 0.5$ ).

**Illustration of a single game.** The X-axis (the Y-axis, respectively) counts the gains of player 1 (player 2, respectively). Each square in Figure A1 represents a potential point. The first square in the lower part of the figure on the left illustrates the starting point in the game (0,0). The square on the right (above) depicts the score if player 1 (player 2) has won the point.

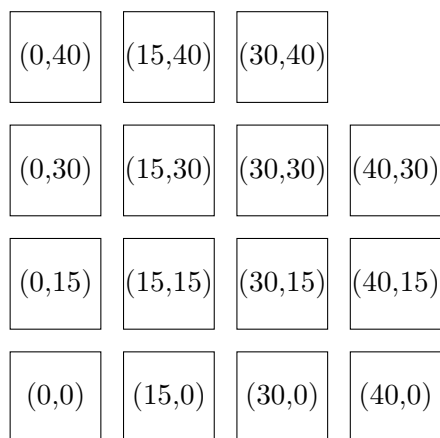


Figure A1: Illustration of a single game.

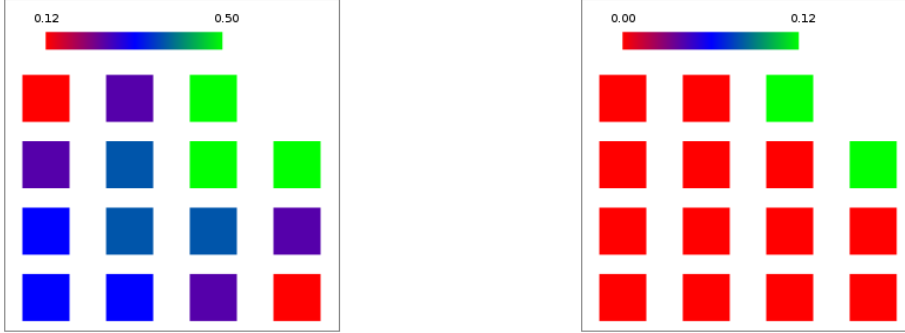


Figure A2: Morris-importance (left) and HNV(1)-importance (right) for all the scores of a single game for  $p = 0.5$ .

**Morris-importance and HNV(1)-importance.** We calculate, for each point, focusing on player 1's point-of-view, both Morris-importance and HNV(1)-importance. We illustrate these results in Figure A2. The following colour codes are used: green means high importance, light blue means somewhat high, dark blue means medium importance, purple means somewhat low importance and red means low importance.

Note that the two panels in Figure A2 are symmetric. Indeed, the probability of winning one point is the same for both players. First of all, Morris-importance is the highest for the scores  $(30,30)$ ,  $(30,40)$  and  $(40,30)$ . Morris-importance is the lowest when the score difference is equal to three points, *i.e.* for the scores  $(0,40)$  and  $(40,0)$ . The closer to the end of the game players are, the less likely will it be for the one who loses this point to win the game. In the case of a single effort left there are only two possibilities: the player has incentives to make an effort or not. Player 1 has positive incentives to exert effort only for  $(30,40)$  and  $(40,30)$ . If player 1 wins at  $(30,40)$ , the score will be a draw  $(30,30)$ , otherwise he will lose the match. In the case of  $(40,30)$ , either he wins the match or there is draw.

We consider five different cases:

- For  $(30,40)$  and  $(40,30)$ , the two measures are similar and high.

- For (30,30) the Morris-importance is high while player 1 has no incentive to make an effort. The intuition is the following. This point is not irreversible. If player 1 loses this point, he can always make an effort subsequently and comes back to draw.
- For (15,15),(30,15) and (15,30), player 1 has no incentives to make an effort. Winning these points modifies the probability of winning the game but these points are not irreversible: it is better to keep the effort and use it latter.
- For scores (0,0), (0,15) and (15,0), Morris-importance is medium while HNV(1)-importance is low.
- For the other scores, the two measures are similar and insignificant.

To conclude, there are only two possibilities: the player has incentives to make an effort or not. The closer to the end of the match players are, the less likely will it be for the player who loses this point to win the game. In other words, the closer to the end of the game the score is, the higher the HNV(1)-importance will be. We also show that the two measures are similar only at the end of a tight game or when the game is fairly one-sided and far from the end.

**Two exhaustible efforts and HNV(2)-Importance.** We also analyze the situation in which the player has two efforts left. Figure A3 depicts HNV(2)-importance for a single game. Note that when player 1 has two efforts left, the points for which he has incentives to use the first effort are clearly different from those for which he has incentives to use the second. The intuition is the following: with two remaining efforts, the goal is to use the first effort to avoid losing the game with a close score and use the last effort to win the game.

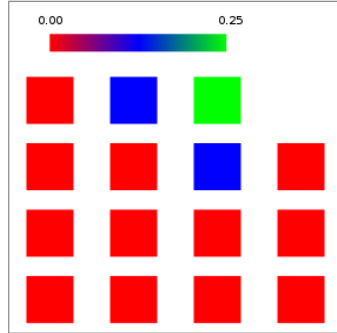


Figure A3: HNV(2)-importance for  $p = 0.5$ .

### A.1.2 Morris-importance and HNV(1)-importance for all the scores of a whole match.

We consider now a whole match and calculate the Morris-importance and the HNV(1)-importance for all the potential points, for the probability  $p=0.5$ . The results for a whole match extend the observations for a single game. Figures A4 and A5 illustrate Morris-importance and HNV(1)-importance for all the scores of a whole match with  $p=0.5$  and where the first player to win two sets is victorious.

- The X-axis (the Y-axis, respectively) displays the gains of player 1 (player 2, respectively).
- Each small square depicts a point. A game is modeled as previously.
- The same rules as in the experiment are used. The first of the two competitors who wins at least 4 points with at least 2 points ahead of the opponent wins the round. The first of the two competitors who wins 6 rounds wins the set. The first of the two competitors who wins 2 sets wins the match.
- We use the same colour codes as previously: high importance (green), somewhat high

importance (light blue), middle importance (dark blue), somewhat low importance (purple), low importance (red).

The figures show that the two measures are similar only at the end of a tight match and when the match is fairly one-sided and far from the end. The notion of irreversibility is crucial. When the match is tight, the individual should make an effort on the tasks which lead to an irreversibility: if this point is lost, the victory is almost impossible.

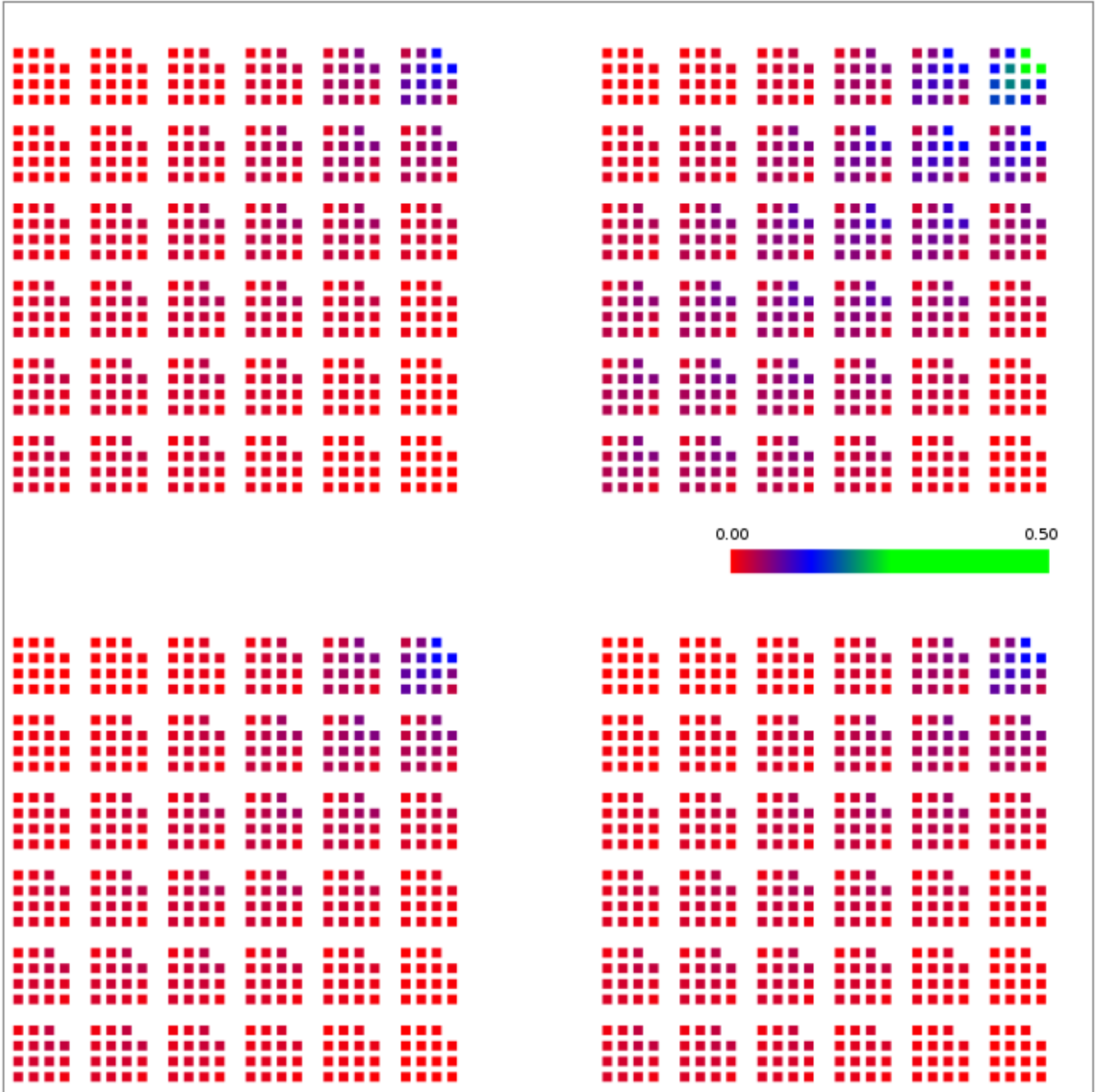


Figure A4: Morris-importance for all the scores of a whole game for  $p = 0.5$ .

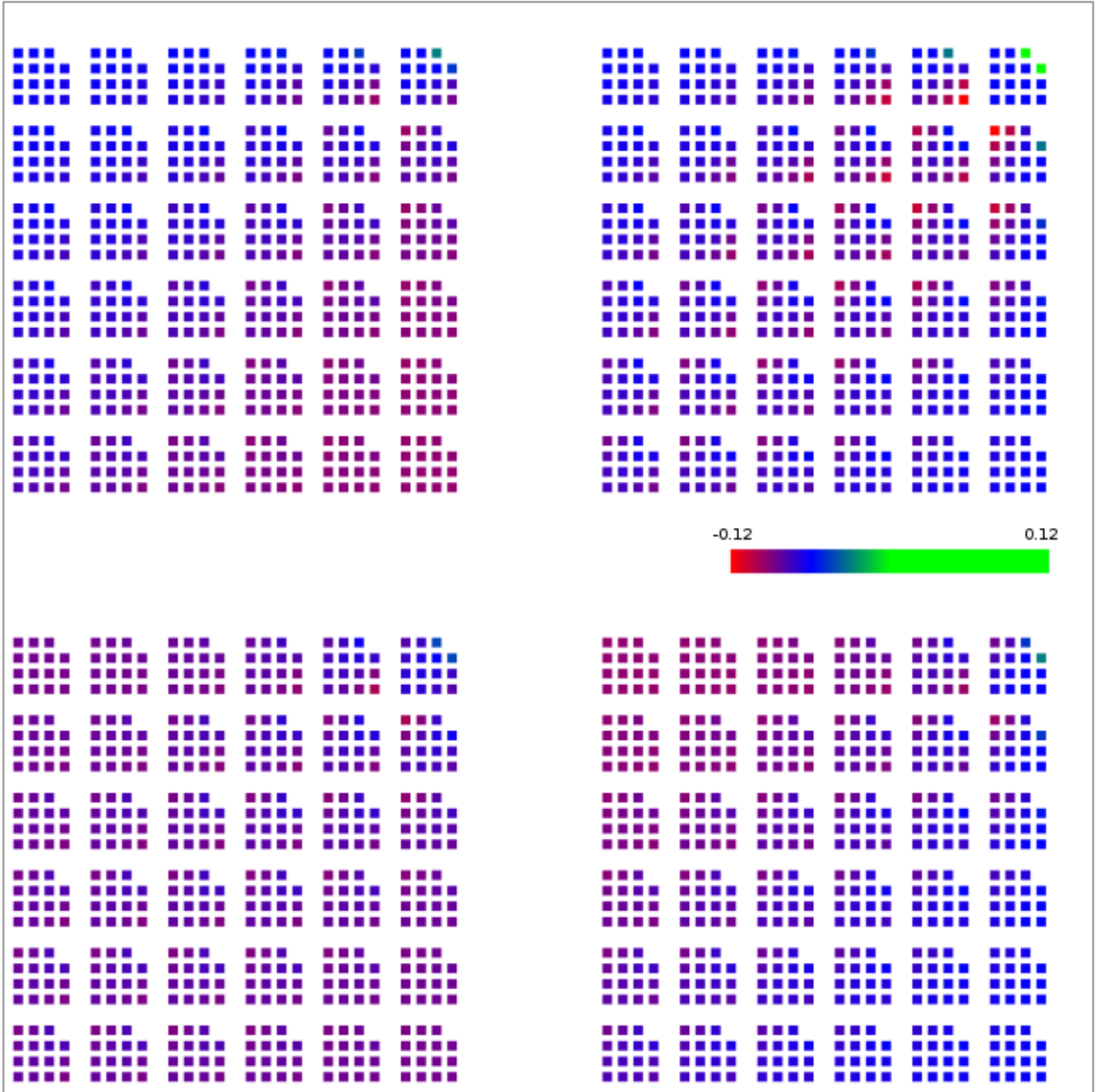


Figure A5: HNV(1)-importance for all the scores of a whole game for  $p = 0.5$ .



## A.2 Instructions for the experiment

*These instructions, translated from French, are both for the Human treatment and the Robot treatment. When the instructions differ between the two treatments, those specific to the Robot treatment are put in italics and between brackets.*

...

We thank you for participating in this experiment in economics in which you can earn a certain amount of money. You will also receive a 5 euros participation fee for showing up on time. You will be paid in cash and in private at the end of the session.

Throughout the session, we ask you not to communicate with other participants. All information entered into the computer will remain anonymous.

### Description

This experiment consists of one part in which you will be paired with one other person in the room. The identity of this person will remain unknown. Similarly, the other person with whom you will be paired will never be informed of your identity. This person will be called your "opponent" in the remainder of these instructions.

*[Previous paragraph replaced by the following in the Robot treatment: This experience consists of one part in which you will be paired with one other player. This player is not a person, it is a computer. This player will be called your "opponent" in the remainder of these instructions.]*

Your earnings in this part depend on your performance and on that of your opponent during the game. In addition to the participation fee, one of the two co-participants will earn 20 Euros and the other will earn 0 Euro, according to the rules detailed below.

*[Previous sentence replaced by the following in the Robot treatment: In addition to the participation fee, you will earn either 20 Euros or 0 Euro, according to the rules detailed below.]*

This part consists of several stages, each of which is divided into several rounds. During each round, we ask you to perform the task described below.

**The task** The task involves using your mouse pointer to reach the center of a target that appears on your computer screen. You have to shoot as accurately as possible in the center of the target. The level of difficulty differs according to a perturbation of the position of the pointer which is random on each shot. The difficulty is the same for each participant.

Each participant has 8 seconds maximum to shoot. If the shot was not performed before the 8 seconds have elapsed, the distance to the target center is arbitrarily set to 1000.

During each round, you will have to shoot several times.

*[Only in the Robot treatment:*

*How does your computer-opponent play?*

*For each shot from your robot, the program randomly selects a shot among the shots of the human participants in a previous session. During this previous session, only human participants were involved and they were paired together randomly. The "robot shot" is therefore not random: it is the shot of a human participant in a previous session aimed at the center of the target.]*

**Performance and number of points** Your performance in this task is indicated by the distance between the impact of your shot and the center of the target. The shorter this distance, the better your performance.

Once the two co-participants have shot, the performances of the two co-participants are compared. The co-participant with the best performance (that is to say, the lowest distance to the center of the target) scores one point.

In case of a tie between the two co-participants, a random draw determines which of the two participants is awarded the point.

The first of the two co-participants who wins at least 4 points with at least 2 points ahead of the opponent wins **the round**.

The first of the two co-participants who wins 6 rounds wins **the set**.

The first of the two co-participants who wins 2 sets wins **the game**.

**Determination of payoffs** Within the pair, if you win the game you earn 20 Euros in addition to your participation fee. If you do not win the game, you earn nothing; you only receive your participation fee.

**Information** As shown in the screenshot below, the screen displays a target. Below the target you can see a time counter that indicates the remaining time to shoot. After each shot, you are informed on your screen of your performance and that of your opponent. Finally, you are informed as to whether you or your opponent scores the current point. The bottom of the screen permanently shows:

- the number of sets won so far,
- the number of rounds won in the current set,
- the number of points earned in the current round, both for yourself and for your opponent.

Your screen also informs you whether the next shot is a shot that decides the winner of the round, the set or game.

**Beginning of the session** Before the game starts, you have to make 5 test shots and 10 practice shots. The five test shots are intended to familiarize you with the task. After each shot, you are informed of your own performance (your distance to the center of the target).

The 10 practice shots are used to calculate your ability at this task compared to that of your opponent. After each of these shots, you are informed of your own performance.

After the 10 practice shots, the computer program compares your performance in each of the 10 practice shots to the performance of your opponent in each of those 10 shots, taking into account all the possible combinations of these shots. The shots that have not been done in the allotted time are not included in this calculation. This calculation will tell you what is the theoretical number of chances out of 100 that you should win the point on your opponent for a given shot.

Your performance during these test and practice shots will not be taken into account in

**Instructions**

Your computer : RIC1

The game will start after 10 practice shots.

The first of the two co-participants who wins 2 sets wins the game.

The first of the two co-participants who wins 6 rounds wins the set.

The first of the two co-participants who earns at least 4 points with at least 2 points ahead wins the round.

The co-participant who wins the game earns €20 in addition to the participation fee. The opponent earns only the participation fee.

Chrono: 7,20

	Set	Round	Point
<b>YOU</b>	1	5	3
<b>OPP</b>	1	5	3

Figure A6: Screenshot of the task.

calculating the points in the actual game.

**End of the session** At the end of the game, you will see on your screen a final questionnaire. Once you have completed this questionnaire, we ask you to wait quietly until the end of the session without communicating with other participants. The session will end once all session participants have finished their games. To wait, you can read the magazines that are available on your desk or any document that you brought with you. You can also enjoy all the activities that will be available on your computer screen.

...

To sum up:

- The task involves shooting at a target.
- The winner of the game earns 20 Euros and the loser gets 0.
- The winner of the game is the one of the two co-participants who won two sets.
- To win a set, one must be the first co-participant to win 6 rounds.\*
- To win a round, one must be the first co-participant to win at least 4 points with at least 2 points ahead of his opponent.

Please read these instructions again and answer the questionnaire that was distributed. If you have any question, please raise your hand and we will answer your questions in private. Once you have completed the questionnaire, raise your hand so we can come and check your answers.

...

## Questionnaire

Thank you for answering these questions to familiarize yourself with the rules of the experiment.

Propositions	Yes	No
<i>[Robot treatment: You play against another person present in the room.]</i>	<input type="radio"/>	<input type="radio"/>
In a round, imagine the current score: 3 points for participant 1 and 2 points for participant 2.		
- Does participant 1 win the round by winning the next point?	<input type="radio"/>	<input type="radio"/>
- Does participant 2 win the round by winning the next point?	<input type="radio"/>	<input type="radio"/>
Does a participant win the set as soon as the participant has won one round more than the opponent?	<input type="radio"/>	<input type="radio"/>
The game ends as soon as a participant has won two sets.	<input type="radio"/>	<input type="radio"/>
The earnings of each set are 20 Euros.	<input type="radio"/>	<input type="radio"/>
There may be three sets in the game.	<input type="radio"/>	<input type="radio"/>
There may be four sets in the game.	<input type="radio"/>	<input type="radio"/>

Table A1: Determinants of performance in the Robot treatment, based on the homogeneous HNV-importance.

Dep. variable:	10 efforts	20 efforts	30 efforts	40 efforts	50 efforts
Distance to center	(1)	(2)	(3)	(4)	(5)
Complexity	0.640*** (0.018)	0.640*** (0.018)	0.640*** (0.018)	0.640*** (0.018)	0.640*** (0.018)
HNV allocation variable	-0.216 (0.247)	-0.084 (0.222)	-0.181 (0.177)	-0.123 (0.189)	0.406 (0.504)
Distance Practice	0.977*** (0.101)	0.976*** (0.100)	0.975*** (0.100)	0.971*** (0.102)	0.975*** (0.100)
Relative ability	0.150 (1.145)	0.135 (1.156)	0.089 (1.183)	-0.141 (1.351)	0.214 (1.137)
Time to shoot	<-0.001 (<0.001)	<-0.001 (<0.001)	<-0.001 (<0.001)	<-0.001 (<0.001)	<-0.001 (<0.001)
Shot number	0.001 (0.002)	0.001 (0.002)	<0.001 (0.002)	<0.001 (0.002)	<0.001 (0.002)
SCR measure	-0.130 (0.095)	-0.131 (0.096)	-0.132 (0.096)	-0.129 (0.095)	-0.128 (0.096)
SCR magnitude	0.905*** (0.303)	0.911*** (0.303)	0.907*** (0.303)	0.916*** (0.302)	0.918*** (0.304)
Male	-0.066 (0.131)	-0.067 (0.132)	-0.066 (0.132)	-0.067 (0.130)	-0.068 (0.131)
Age	-0.018 (0.012)	-0.019 (0.012)	-0.019 (0.012)	-0.019 (0.012)	-0.019 (0.012)
Tennis	-0.083 (0.092)	-0.081 (0.091)	-0.083 (0.091)	-0.074 (0.089)	-0.076 (0.091)
Constant	-4.223*** (1.155)	-4.190*** (1.152)	-4.127*** (1.178)	-3.999*** (1.338)	-4.219*** (1.147)
Nb observations (clusters)	5100 (33)	5100 (33)	5100(33)	5100 (33)	5100 (33)
F	487.79	465.35	464.18	511.24	463.56
p>F	<0.001	<0.001	<0.001	<0.001	<0.001
R2	0.192	0.192	0.192	0.192	0.192

Notes: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\*, \*\* and \* indicate significance at the 1% level, 5% level and 10% level, respectively.

Table A2: Determinants of performance (distance to the center)

Dep. variable:	Morris criterion		HNV criterion in the Human treatment						
	Human (1)	Robot (2)	10 efforts (3)	20 efforts (4)	30 efforts (5)	40 efforts (6)	50 efforts (7)		
Distance									
Complexity	0.633*** (0.015)	0.644*** (0.018)	0.633*** (0.015)	0.633*** (0.015)	0.633*** (0.015)	0.633*** (0.015)	0.633*** (0.015)	0.633*** (0.015)	
Morris criterion	-0.117 (0.540)	-4.612 (2.769)	-	-	-	-	-	-	
HNV allocation variable									
Time to shoot			-0.310** (0.131)	-0.313*** (0.116)	-0.343*** (0.095)	-0.090 (0.098)	-0.852*** (0.254)		
Shot number	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)		
SCR measure	-0.001 (0.001)	0.001 (0.003)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)		
SCR magnitude	-0.049 (0.110)	-0.043 (0.321)	-0.050 (0.109)	-0.051 (0.109)	-0.043 (0.109)	-0.049 (0.110)	-0.048 (0.110)		
Male	0.023 (0.371)	0.732** (0.303)	0.030 (0.371)	0.032 (0.373)	0.020 (0.373)	0.033 (0.374)	0.028 (0.375)		
Age	0.039 (0.102)	-0.180 (0.326)	0.040 (0.102)	0.038 (0.102)	0.040 (0.102)	0.042 (0.103)	0.036 (0.102)		
Tennis	0.025*** (0.006)	0.018 (0.045)	0.024*** (0.006)	0.025*** (0.006)	0.025*** (0.006)	0.025*** (0.006)	0.024*** (0.006)		
Constant	-0.026 (0.106)	-0.004 (0.362)	-0.030 (0.103)	-0.028 (0.104)	-0.025 (0.104)	-0.025 (0.104)	-0.028 (0.104)		
Nb observations (clusters)	2.103*** (0.232)	2.817* (1.407)	2.116*** (0.231)	2.140*** (0.231)	2.169*** (0.233)	2.111*** (0.233)	2.102*** (0.233)		
F	10640 (70)	5100 (33)	10640 (70)	10640 (70)	10640 (70)	10640 (70)	10640 (70)		
p>F	364.02	437.41	357.09	357.22	365.57	361.41	368.28		
R2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
	0.234	0.182	0.234	0.234	0.234	0.234	0.234		

Notes: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\*, \*\* and \* indicate significance at the 1% level, 5% level and 10% level, respectively. Models (1) and (2) correspond to models (4) and (5) in Table 5; Models (3) to (7) correspond to models (1) to (5) in Table 6.



Table A3: Determinants of performance in the Human treatment, based on the homogeneous HNV-importance and Morris-importance.

Dep. variable: Distance to center	10 efforts (1)	20 efforts (2)	30 efforts (3)	40 efforts (4)	50 efforts (5)
Complexity	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)
HNV allocation variable	-0.310** (0.127)	-0.336*** (0.114)	-0.374*** (0.097)	-0.187* (0.095)	-0.998*** (0.264)
Morris criterion	0.153 (0.516)	0.313 (0.512)	0.495 (0.521)	0.169 (0.527)	0.178 (0.261)
Distance Practice	0.265** (0.116)	0.263** (0.116)	0.259** (0.115)	0.260** (0.115)	0.265** (0.117)
Relative ability	-2.687** (1.194)	-2.782** (1.185)	-2.897** (1.180)	-3.003** (1.200)	-2.794** (1.204)
Time to shoot	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)
Shot number	-0.001 (0.001)	-0.001 (0.001)	-0.002 (0.001)	-0.001 (0.001)	-0.001 (0.001)
SCR measure	-0.052 (0.071)	-0.056 (0.071)	-0.049 (0.071)	-0.055 (0.072)	-0.052 (0.071)
SCR magnitude	-0.092 (0.326)	-0.098 (0.327)	-0.104 (0.327)	-0.091 (0.329)	-0.100 (0.329)
Male	-0.008 (0.066)	-0.009 (0.066)	-0.007 (0.066)	-0.004 (0.067)	-0.012 (0.066)
Age	0.021*** (0.006)	0.021*** (0.006)	0.021*** (0.006)	0.022*** (0.006)	0.021*** (0.006)
Tennis	-0.116 (0.082)	-0.115 (0.082)	-0.114 (0.082)	-0.111 (0.082)	-0.115 (0.082)
Constant	1.568 (1.269)	1.659 (1.269)	1.783 (1.258)	1.766 (1.264)	1.609 (1.276)
Nb observations (clusters)	10640 (70)	10640 (70)	10640 (70)	10640 (70)	10640 (70)
F	318.17	313.72	317.22	319.52	332.66
p>F	<0.001	<0.001	<0.001	<0.001	<0.001
R2	0.237	0.237	0.237	0.237	0.237

Note: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\*, \*\* and \* indicate significance at the 1% level, 5% level and 10% level, respectively.

Table A4: Determinants of performance in the Human treatment, based on the homogeneous HNV-importance and type of shots.

Dep. variable: Distance to center	10 efforts (1)	20 efforts (2)	30 efforts (3)	40 efforts (4)	50 efforts (5)
Complexity	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)	0.631*** (0.015)
HNV allocation variable	-0.108 (0.138)	-0.176 (0.127)	-0.252** (0.106)	-0.073 (0.097)	-1.025*** (0.255)
Round shot for i	-0.312*** (0.105)	-0.277** (0.110)	-0.255** (0.113)	-0.314*** (0.105)	-0.329*** (0.104)
Set shot for i	-0.240 (0.304)	-0.217 (0.307)	-0.170 (0.311)	-0.248 (0.304)	-0.256 (0.303)
Match shot for i	0.254 (0.289)	0.254 (0.286)	0.254 (0.286)	0.247 (0.288)	0.244 (0.288)
Round shot for j	0.003 (0.086)	0.001 (0.086)	0.007 (0.086)	0.007 (0.086)	0.003 (0.086)
Set shot for j	-0.357 (0.321)	-0.316 (0.315)	-0.278 (0.318)	-0.365 (0.319)	-0.398 (0.321)
Match shot for j	-0.966*** (0.267)	-0.920*** (0.264)	-0.858*** (0.253)	-0.974*** (0.251)	- -
Distance Practice	0.264** (0.115)	0.263** (0.115)	0.259** (0.114)	0.262** (0.115)	0.264** (0.115)
Relative ability	-2.756** (1.207)	-2.809** (1.206)	-2.900** (1.180)	-2.879** (1.227)	-2.757** (1.204)
Time to shoot	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)	<0.001 (<0.001)
Shot number	-0.001 (0.001)	-0.001 (0.001)	-0.002 (0.001)	-0.001 (0.001)	-0.001 (0.001)
SCR measure	-0.052 (0.071)	-0.054 (0.070)	-0.049 (0.070)	-0.053 (0.071)	-0.052 (0.071)
SCR magnitude	-0.096 (0.325)	-0.098 (0.326)	-0.108 (0.326)	-0.097 (0.327)	-0.101 (0.326)
Male	-0.010 (0.067)	-0.011 (0.066)	-0.010 (0.066)	-0.009 (0.067)	-0.011 (0.067)
Age	0.021*** (0.006)	0.021*** (0.006)	0.021*** (0.006)	0.022*** (0.006)	0.021*** (0.006)
Tennis	-0.114 (0.081)	-0.114 (0.082)	-0.112 (0.081)	-0.113 (0.081)	-0.113 (0.082)
Constant	1.630 (1.264)	1.678 (1.268)	1.773 (1.258)	1.707 (1.276)	1.627 (1.262)
Nb observations (clusters)	10640 (70)	10640 (70)	10640 (70)	10640 (70)	10640 (70)
F	253.80	254.55	263.28	254.62	270.41
p>F	<0.001	<0.001	<0.001	<0.001	<0.001
R2	0.237	0.237	0.237	0.237	0.237

Note: All models are OLS regressions with robust standard errors (in parentheses) clustered at the individual level. \*\*\*, \*\* and \* indicate significance at the 1% level, 5% level and 10% level, respectively.